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East Maui (Haleakala volcano) rises 3054 m above the ocean, and clouds intercepting the mountain slopes are an integral part of the climate. To what extent do the trees and shrubs on the mountainsides extract cloud water that contributes to soil moisture, groundwater recharge, and stream flow in the watersheds? Two sites, on the windward and leeward sides of the mountain, were instrumented to study this process. Weather stations at each site measured climate parameters, and stable isotopes of fog, rain, soil water, stream flow and tree sap were measured monthly to track the proportion of cloud water in the forest hydrologic system. When clouds envelop a forest, the precipitation ranges from light mist to rain, leading to difficulties in measuring cloud water as opposed to rainfall. Deposition of cloud water depends on wind speed, droplet size, surface area of the vegetation, and many other factors. Cloud water deposition was measured on a continual basis using a vertical screen collector, which did not exclude rainfall. The fog isotope collectors did exclude vertically falling rain, and cumulative monthly fog volumes were compared with volumes from isotope rain collectors. Throughfall collectors provided information on the efficiency of the vegetation in collecting cloud water (fog drip). At the windward site, fog screen/ rain gage volume ratios normalized to collection area ranged from 0.74-4.9, with a median value of 1.5. The median fog/ rain ratio from the isotope collectors (normalized to surface area) was 0.35. The screen collector cannot be directly extrapolated to forest canopy, but the data suggest substantial impaction of cloud water on vegetation surfaces exposed to the wind. Isotopic composition of stream water reflected recent precipitation, including cloud water, while the soil water had a larger proportion of precipitation from large rainstorms. *Metrosideros polymorpha* tree sap isotopic composition was sometimes identical to fog drip, almost never similar to soil water, and generally appeared to be a mixture of fog drip and rainfall. The leeward site was deforested in the early part of the 20th century, and has remnants of cloud forest. Most water input is from infrequent large storm systems, while the clouds that envelop the site on a more frequent basis have relatively low water content. Fog screen/ rain gage volume ratios here ranged from 0.21-13.5, with a median value of 0.70. The median fog /rain ratio from the isotope collectors was 0.21. Soil water isotopic composition reflected the large rainstorms, with little cloud water input. Isotopic composition of M. *polymorpha* sap at this site was similar to soil water, suggesting that the trees tap a deeper water source than at the windward site. Results from the study will lead to a better understanding of the relationship of cloud forests to recharge and streamflow along mountain slopes.

URL: http://water.usgs.gov/nrp/proj.bib/hawaii/maui_fog.htm

H32E-05 1500h

Persistent Spatial Variability of Throughfall Amounts and Intensity Beneath Forest Canopies

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Forest canopies are important modifiers of precipitation, both spatially and temporally. Because of the nonlinearities in water fluxes through soils, understanding precipitation redistributions in space and time will allow advances in predicting rainfall-runoff processes in forested watersheds. We found distinct spatial patterns of throughfall persisting in time in three forest stands in the Pacific Northwest, USA. Variograms of storm-total throughfall, collected in small gauges, differed by stand but were consistent among storms within each site. Nondimensionalizing throughfall amounts in the small gauges revealed persisting wet and dry areas, which preserved variograms through time deterministically instead of simply statistically. Cumulative distribution functions of study-total throughfall at each gauge were useful for characterizing persistence of throughfall variability. We measured throughfall intensity within storms using larger throughfall gauges attached to tipping buckets. By comparing these data to rain gauges in nearby openings, we quantified attenuation of rainfall intensity by canopies. There was both temporal and spatial variability in intensity attenuation. Spatial variability was low under a homogeneous canopy of young conifers, but high under a heterogeneous canopy of old-growth conifers. High intensity attenuation was generally correlated with low storm-total throughfall. These persisting patterns in throughfall amounts and intensity suggest there may be corresponding variation in infiltration and soil water movement.

H32E-06 1515h

Linkages between soil respiration and its physical and biological drivers at multiple spatial scales in a lodgepole pine (*Pinus contorta*) forest

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The purpose of this study was to characterize the relationships between soil respiration and some physical and biological properties of the soil that drive it, including soil temperature, soil water content, and litter depth. We also examined spatial patterns of each factor at the hillslope scale (13,000 m^2) and the individual plot scale (25 m^2) to identify spatial correlations using geostatistics. Our study area in the Medicine Bow Mountains of Wyoming encompasses adjacent North- and South-facing slopes at 2800 m elevation. Lodgepole pine (*Pinus contorta*) forest dominates the watershed, and spruce (*Picea engelmannii*), fir (*Abies lasiocarpa*) , and aspen (*Populus tremuloides*) are also present where soils are moist. Within each spatial scale, semi-variograms were used to identify the spatial range of soil respiration and its drivers. At the plot scale, soil respiration drivers exhibited stronger spatial patterns than soil respiration. At the hillslope scale, aspect played an important role in the relationships between soil respiration and these drivers. Drivers of soil respiration are still poorly understood at varying spatial scales; this project aims to better quantify these linkages for improved modeling of carbon fluxes at the watershed scale.

H32F MCC: 3022 Wednesday 1340h

Watershed Processes and Linkages to Regional and Watershed Patterns in Stream Channel Morphology I

Presiding: **J M Faustini,** Oregon State University**; B P Bledsoe,** Colorado State University

H32F-01 1345h INVITED

Hydraulic Control on the Spatial Distribution of Chinook Salmon Spawning Gravels in Central Idaho: Integrating Reach-Scale Predictions via Digital Elevation Models

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We examined hydraulic controls on the spatial distribution of chinook salmon spawning gravels in the Middle Fork Salmon River, a mountain basin in the Frank Church Wilderness of central Idaho. Reach-scale predictions of substrate size were integrated via a digital elevation model (DEM) to assess the basin-scale distribution of spawning gravels. Channel reaches were delineated between 40' contour intervals within the DEM, and were further subdivided at tributary junctions. Reach-scale predictions of channel competence (size of sediment that can be carried by the channel) were determined from the Shields equation evaluated at bank-full stage and empirically adjusted for local channel roughness and sediment supply (both as functions of bank-full shear stress). We use the bank-full shear stress because channel morphology and sediment size in coarse-grained rivers are commonly adjusted to bank-full flow. Shear stress in the Shields equation was predicted from a depth-slope product, with bank-full depth determined from a basin-specific hydraulic geometry relationship (expressed in terms of drainage area), and channel slope was determined from the DEM. Data for the empirical relationships were derived from field measurements of 121 channel reaches. The final grain-size prediction is a function of drainage area and slope, values readily obtained from the DEM. Field observations of chinook salmon spawning sites within the study area were used to define preferred substrate sizes. Predicted grain sizes were compared to preferred values to determine the basin-scale distribution of suitable spawning gravels. To test the model, predicted spawning-gravel sites were compared to an 8 year record of observed redd locations. Results demonstrate that nearly 90% of the redds (n=5135) occurred within reaches predicted to have suitable substrate sizes, with 98% of those reaches predicted to have a pool-riffle morphology. Moreover, redd densities were roughly 3 times greater in reaches predicted to be suitable. However, redds tended to be clustered in upstream portions of the accessible network, rather than evenly distributed throughout the suitable reaches. This may be due to a variety of factors, including 1)depressed population sizes and preferential selection of the best spawning sites; 2)loss of chinook salmon phenotypes that once spawned in currently underutilized habitats, and fidelity of remaining subpopulations; or 3)constraints imposed by environmental factors other than substrate size (e.g., stream temperature, velocity, scour regime, hyporheic flow, winter icing, etc.). Sources of error in our predictions are largely due to scatter in the correction for channel roughness and sediment supply. Correspondence between observed channel slopes and those predicted from the DEM are reasonably good. Although reach-scale predictions perform well, spawning site selection likely depends on subreach hydraulics and textural patches that are not accounted for in our analysis. Nevertheless, subreach textural variability can be associated with reach-scale channel type, allowing empirical adjustment for the potential subreach area available for spawning.

H32F-02 1405h INVITED

How to Reach Across a Basin: Integrating Basin-Scale Interactions to Reach-Scale Predictions

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Many reach-scale aspects of channel morphology, habitat structure, and disturbance regime arise from basin-scale interactions. Valley-floor landforms and channel types reflect a potentially long history of events that have mobilized sediment from upstream and upslope. Processes that move sediment and woody debris act over a basin topography that controls the location of sediment delivery to channels. Subsequent movement and fluvial rearrangement of this sediment is modulated by valley morphology and channel-network structure. These controls on sediment production, movement, and storage can be inferred using digital elevation data coupled with simple models of sediment mobilizing processes. This characterization of the active processes can then be used to infer the spatial distribution of channel morphology and habitat structure. Coupled with climatic and anthropogenic drivers that produce temporal variability in the rate of sediment and wood production (storms, fires, road construction), these tools can be used to characterize channels throughout a basin in terms of the distribution of morphologies and habitat structures that can arise at each reach. We'll describe GIS modeling tools developed for debris-flow-prone landscapes of the Pacific Northwest and describe our strategy for verifying and using model predictions.

H32F-03 1425h

Detecting Cumulative Effects on Low-gradient Streams in the Central Sierra Nevada, California

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Cumulative watershed effects (CWEs) result from multiple activities over time and space. The assessment of CWEs in the Sierra Nevada is severely limited by the lack of field data on the effects of a given action, the lack of models to predict the effects of multiple actions at the watershed scale, and the limited data relating stream channel conditions to measured or predicted changes in sediment yields. Since 1999 we have been measuring hillslope-scale sediment production rates from roads, timber harvest, wildfires, and minimally-disturbed areas. From these and other data we are developing models to predict sediment production rates from different land uses. The next, more difficult step in developing a reliable CWE model is to compare predicted changes in catchment-scale sediment production rates to stream channel conditions. Channel conditions were measured in 28 pool-riffle reaches in the American and Cosumnes river basins. Contributing areas ranged from 2.9 to 70 km2, and the elevations of the reaches ranged from 1200 to 1800 m. The basins were selected to encompass a wide range in the amount of natural and anthropogenic disturbance. Variables used to characterize the amount of disturbance include road density, number of road crossings, modeled road sediment production, percent forest harvest, and the percent burned by wildfire. The data collected in each reach included gradient, channel dimensions, grain size, amount of large woody debris, and pool size and sediment infill. Preliminary results indicate that basins with more than 20% of the area in granitic lithologies have significantly more fine sediment coverage in pools (r2=0.35; p=0.0002). The fine sediment coverage in pools also was correlated with the amount of large woody debris. After removing the variability due to lithology and basin area, there was a significant, positive correlation between the estimated sediment production from unpaved roads and residual pool infill volume (r2=0.14; p=0.02). Other than these relationships, there appear to be no significant correlations between the measured channel characteristics and the amount of disturbance. The limited number of significant correlations may be a consequence of a record flood event in early 1997. This event may have effectively "reset" the stream channels, resulting in a lower detectability of cumulative watershed effects.

H32F-04 1440h

Sedimentation in Pacific Northwest Coastal Streams – Evidence from Regional Surveys of Bed Substrate Size and Stability

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We examined evidence of anthropogenic sedimentation in Oregon and Washington coastal streams using relatively rapid measurements taken from surveys during summer low flows (probability sample, n= 104 reaches). We inferred bankfull channel dimensions from evidence at low flow and compared bed substrate geometric mean diameter (Dgm) with critical diameter (D*cbf) calculated from estimated bed shear stress at bankfull flow stage. We derived an index of Relative Bed Stability, RBS* = Dgm / D*cbf , based on a modified Shield's criterion for incipient motion that includes adjustments to bed shear stress for energy dissipated by large wood and channel irregularities. D*cbf averaged 56 percent of unadjusted values, and Dgm ranged from silt to boulder size. Log10[RBS*] in streams relatively undisturbed by humans was generally between -0.7 and +0.5, showing approximate balance between observed and mobile substrates, but declined to low values (-1.5 to -3.0) in streams with substantial riparian and basin disturbances. Streams draining soft sedimentary lithology showed greater apparent response to these disturbances than did those draining hard basalt lithology. The association of low RBS* with land disturbance, and the stronger absolute values of correlation of Dgm (negative) than D*cbf (zero or positive) with land disturbance in this region strongly suggest that activities including road building, land-clearing, logging and agriculture have augmented sediment supplies and increased fine sediments in stream beds.

H32F-05 1455h

Morphological Effects of Channel Confinement and Riparian Vegetation on Urban and Non-urban Streams of the Pacific Northwest

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The morphological influences of the near-riparian zone on channel morphology and channel responsiveness to urbanization were analyzed in low- and high-urbanized watersheds. Study sites included 22 reaches in a low-urbanized system on the Kitsap Peninsula in western Washington State, paired with 22 reaches having comparable slopes and drainage areas from highly urbanized watersheds in and east of the City of Seattle. Remarkably different channel morphologies were observed between low and high-urbanized reaches. Low-urbanized reaches displayed mainly forced pool-riffle morphology; the high-urbanized reaches were dominated by constrained (armored) step-pool and plane-bed morphologies. In comparison, the low-urbanized reaches had less bank erosion and more in-stream wood, pools, and sediment storage. In low-urbanized watersheds, channel morphology (as quantified by measures of in-stream wood frequency and distribution, pool frequency, sediment storage, and bank erosion) was related to the degree of channel confinement and to characteristics of the near-riparian vegetation. High-urbanized reaches, in contrast, were substantially less sensitive to the condition of the near-riparian zone due to the common stream disconnection with the floodplain triggered by the placement of bank-armoring structures. From a management perspective, an increase in woody debris in plane-bed reaches could yield an eventual morphologic shift to forced pool-riffle. However, increased wood loading in these channels does not guarantee such a shift. These channels also need to be reconnected to their forested floodplain and to the channel-bank sediment, which provide long-term sources of both large woody debris and gravel. In the case of anthropogenically confined channels, restoration is even more challenging because sustainable morphologic improvements would require removal of bank-armoring structures to facilitate that reconnection. The common practice of adding logs results in short-term improvements, but is not likely to provide a sustainable solution in many settings unless equal consideration is given to geomorphic processes that maintain floodplain connectivity.

H32F-06 1510h

Case Studies in Quantification and Mapping of Stream Channel Morphology in the Pacific Northwest: Lessons From Past Efforts and Recommendations for Future Studies, Montana, and Northern California

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Watershed analysis seeks to identify patterns in channel geomorphology and sensitivity of different channel types to management influences. Although most analyses succeed in identifying patterns in the distribution of stream channel morphology and develop reasoned hypotheses regarding effects of past and future management, these conclusions generally rely on extrapolation of trends with high statistical variance. Field data are rarely collected in sufficient quantity and precision to satisfy common standards of statistical rigor. Nevertheless, field data form the basis for conclusions regarding watershed form and process. This paper reviews data from previous analyses in Washington, Montana, and northern California to gain insights regarding limitations on collection of data sets for rigorous analyses, including both high statistical variance in fluvial systems and cost of field surveys. Recommendations for techniques and protocols to develop rigorous field data sets that can be combined with remote sensing data to produce improved watershed scale assessments are offered. These methods are suitable for developing monitoring baseline surveys, which can be utilized for either long-term monitoring and adaptive management experiments.

H32F-07 1525h INVITED

Regression Models That Relate Streams to Watersheds: Coping With Numerous, Collinear Predictors

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GIS efforts can produce a very large number of watershed variables (climate, land use/land cover and topography, all defined for multiple areas of influence) that could serve as candidate predictors in a regression model of reach-scale stream features. Invariably, many of these candidate predictors are correlated with each other, leading to ambiguities in regression model choice, prediction and interpretation. Strategies for coping with collinearity and model choice are illustrated, using watershed and stream data collected from the Willamette Basin in Oregon. Collinearity can greatly inhibit one's ability to determine the relative importance of individual predictors. Sometimes it is easier and clearer to assess the relative importance of groups of conceptually-similar predictors (for example, "natural-gradient" versus "human disturbance" predictors). In addition, one can estimate the amount of model-explained variance in a response variable that is shared by multiple predictors and hence cannot be disentangled. Finally, if multiple, collinear variables are considered as candidate predictors, then model development will likely yield several "best" models, all of them believable and all of them nearly equal in their quality of fit. In this case, one can carry out model averaging of predictions, of relative importance measures, or of the effects of an individual predictor.

H32G MCC: 3024 Wednesday 1600h

Environmental Impacts of Coal-Bed Methane Development I *(joint with B, GC)*

Presiding: **R W Healy,** U.S. Geological Survey**; R L Smith,** U.S. Geological Survey

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H32G-01 1600h

Montana's Coalbed Methane Ground-Water Monitoring Program: Year One

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Tertiary coal seams in the Powder River Basin in southeastern Montana provide three very important resources: ground water, coal, and natural gas. Ground water from springs and wells is essential for the local agricultural economy. Because coal seams in the Fort Union Formation have higher hydraulic conductivity values and are more continuous than the sandstone units, they are the primary aquifers in this region. Coalbed methane (CBM) production is beginning in the Powder River Basin, and requires removal and management of large quantities of water from the coal-seam aquifers. The extensive pumping required to produce the methane is expected to create broad areas of severe potentiometric decline. The Montana CBM ground-water monitoring program, now in place, is based on scientific concepts developed during more than 30 years of coal-mine hydrogeology research. The program includes inventories of ground-water resources and regular monitoring at dedicated wells and selected springs. The program is now providing baseline potentiometric and water-quality data, and will continue to be active through the duration of CBM production and post-production ground-water recovery. An extensive inventory of ground-water resources in the Montana portion of the Powder River Basin has located 300 springs and 21 wells on private land, and 460 springs and 21 wells on U. S. Forest Service and U. S. Bureau of Land Management land, all producing ground water from the methane bearing strata. In southeastern Montana, 134 monitoring wells are currently included in the CBM monitoring program. They are completed either in coal seams, adjacent sandstone units,