evaluated for different loading paths and is found to be largely controlled by a simple parameter, the driving stress ratio (R), where R = 2 x (fluid pressure - mean stress) / (differential stress). In numerical models of highly fractured rock, the critical stress state R_C can be demonstrated to depend mainly on the frictional properties of the fractures, with other parameters (e.g. fracture geometry, density and rock rheology) controlling the form of the resulting deformation and localization of fluid flow. In most cases the critical driving stress ratio (R_C) is between -2 and -1.5. A common feature of a critically stressed fracture network is the localized nature of the fluid flow. In situ stress measurements, especially those from deep boreholes and producing oil reservoirs, indicate that driving stress ratios, R, are -2 or higher. In some cases where stress changes locally, either naturally or through human intervention, R remains constant. These observations agree well with numerical models and strongly support the idea that much of the upper crust is maintained at or close to the critical stress state. In such cases, localization of flow should be characteristic.

H52A MCC: Level 2 Friday 1330h

Fluvial Geomorphology Posters

Presiding: **E B Safran,** Lewis and Clark College**; E Wohl,** Colorado State University

H52A-1138 1330h POSTER

Channel Initiation Processes in Basalt and Sandstone Lithologies in Southwest Washington

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A persistent problem for managers of headwater streams has been accurately identifying where these headwater channels begin on the hillslope and determining the physical extent of the channel network. This problem is exacerbated by the relatively few published field data on both channel-head locations and initiation processes in forested landscapes of different lithologies. Several workers have presented the theory that channel-head locations are a function of an inverse slope-drainage area relationship. We hypothesized that channel-head locations in a fine-grained basalt lithology would be independent of slope. In sandstone, we expected channel-head locations to follow the inverse slope-drainage area relationship. In addition, we hypothesized that seasonal migration of surface water presence would reflect a near-surface hydrologic process whereas surface water flowing from the same location throughout the year would reflect a groundwater control. Seventy-eight channel-heads were mapped using a high resolution Global Positioning System in basalt and sandstone lithologies in southwest Washington. Source areas for these channel-heads ranged between 600 m^2 and 50,000 m^2 and local slopes ranged between 15% and 80%. The upslope extent of surface water was monitored and mapped for 14 basalt and 20 sandstone streams. Watersheds were monitored monthly from February through November 2003. Initial analyses have indicated that local slope does not correlate with channel-head locations in either basalt or sandstone lithologies. However, contributing areas with similar local slopes were significantly larger in basalt compared to certain sandstone lithologies. Observations from the surface water mapping suggest that the channel initiation processes within the basalt lithology are groundwater controlled versus the near-surface hydrologic control observed within the sandstone lithology. As a result, underlying lithology remains a major control on processes driving channel initiation and channel-head locations in high-gradient, lowland watersheds.

H52A-1139 1330h POSTER

Channel Initiation and Competition in Tidal Environments

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Numerical simulations are presented on the initial formation and on the competition of tidal channels evolved within youthful salt marsh environments. We present a model that simulates the evolution of tidal channel cross sections, by coupling calculations of bottom shear stresses due to tidal motions with erosion, taking into account the deposition of cohesive and noncohesive sediments. The simulations characterize the morphodynamic evolution of a reference cross section composed of incipient channels and of marsh surface zones. The discharges that shape the section vary in time as a surrogate of the tidal level with a quasi-static model. Wetting and drying cycles are therefore considered. We analyze, at first, the driving factors which lead to the actual observed channel cross sections in tidal basins, starting from the initial channel formation to their long term morphodynamic evolution. In particular, it is shown that large temporal gradients of leading flow rates induce important temporal variabilities of channel geometry in time. The local and temporary evolution of tidal channels, dictated by tidal flow rates, allows the identification of the chief landscape forming discharges. In the second part of our study we simulate the competition of tidal channels evolving within an assigned tidal flat. In these simulations the calculation of the characteristic distance between adjacent forming channels makes it possible to study the drainage density of salt marshes.

H52A-1140 1330h POSTER

Is the Profile of the Colorado River in the Colorado Plateau in Equilibrium With Bedrock?

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The Colorado River sets the pace for the erosion of the Colorado Plateau and part of the Rocky Mountains, and the evolution of its long-profile may hold the key to resolving debate over the region's late Cenozoic erosional and tectonic history. Significant reach (10 km) and canyon-scale (100 km) gradient variations occur along the modern profile of this mixed bedrock-alluvial river, and there are multiple hypotheses for the controls on its gradient: 1) knickzones related to active tectonics in western Grand Canyon, 2) coarse bed material from tributary side-canyons, and 3) bedrock resistance as a direct control with respect to channel substrate or an indirect control in terms of hillslope processes in tributary catchments and the production and comminution of bed material. The goal of this study is to test for a spatial relation between hydraulic driving forces and bedrock resisting forces at reach and canyon-scales within and between Glen and Grand canyons. The river encounters diverse rock types that vary in hardness and fracture density. Field and GIS results aimed at testing the bedrock resistance hypothesis for Glen and Grand canyons indicate a spatial relation between rock-mass strength (RMS) and channel gradient. Reach-scale gradients vary as much as a factor of 20 through Grand Canyon, with steep reaches having significantly higher compressive strengths and wide fracture spacings. Glen Canyon, on the other hand, has dramatically lower channel gradient, weaker RMS properties, and reaches with steep gradients that do not correlate to either debris fans or changes in bedrock type but do coincide with geologic structures. The presence of a bedrock or debris-fan frequency correlation to the majority of gradient variations argues against tectonic origins of knickzones and suggests a relation between bedrock resistance and the profile of the Colorado River exists. However, when these results are combined with the distribution of tributary debris fans and their control on the channel organization as detailed by other workers in Grand Canyon, there is a complex spatial correlation between bed material, rock-type, and channel gradient, preventing the direct inference that the river is in equilibrium with bedrock.

H52A-1141 1330h POSTER

Knickpoint retreat and landscape disequilibrium on the James River from the Piedmont through the Valley and Ridge, central Virginia, USA

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Several lines of evidence indicate landscape disequilibrium in the James River basin in central Virginia. The river longitudinal profile possesses pronounced convexities and apparently migratory knickzones. Along much of its length, it flows in a narrow inner valley incised into a discontinuous, low-relief upland. In the inner Piedmont, the 150 m wide river channel occupies an incised valley that can be as little as 600 m wide and 75 m deep. Broad fluvial terraces are often found capping the high topography directly adjacent to the valleys, and we use these disconnected terraces to reconstruct paleo-river profiles spanning 200 km in the Piedmont. These high, extensive terraces disappear in the James River Gap through the Blue Ridge, but reappear with less distinction in the carbonate rocks of the Great Valley. The river remains incised within the Great Valley, with prominent knickzones 60-100 km above the Blue Ridge gap found on both the mainstem and tributaries. We dated terraces in the Piedmont with in-situ 10Be profiles and a depth integration technique. Dates from the highest terrace level at three locations along 100 km of the river are 1 m.yr., suggesting rapid river incision rates of 55 m/m.yr. We also have documented exceptionally high incision rates along a tributary in the Great Valley. This dating suggests disequilibrium erosion was initiated and has persisted here during the late Quaternary. Assuming the incision is accomplished largely by knickpoint retreat, the dates suggest past retreat rates of up to one m/yr in the Piedmont and 250 m/m.yr. between the outer Piedmont and the Great Valley. We have two hypotheses for how this recent incision was triggered: 1) response to flexural-isostatic uplift generated by drainage basin capture and associated denudation and/or 2) the shift to more rapid climate fluctuations in the early Pleistocene. Additionally, we suggest two interpretations for the generation of the extensive high terrace surfaces. They may be valley floor remnants of a broad alluvial upland incised by a migrating knickpoint, or remnants of a broad valley floor developed at the base of knickpoints that have now migrated upstream along the profile.

H52A-1142 1330h POSTER

Quantifying the Convexity of Waterfalls Along the Niobrara River, Cherry, Keya Paha, and Brown Counties, Nebraska

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Numerous waterfalls are present along the spring branch canyons of the Niobrara River, downstream of Cornell Dam, Valentine, Nebraska. Although the sizes of the waterfalls are variable, a majority of the waterfall faces have a convex outward geometry. In order to gain a better understanding of the processes responsible for the development of this profile, it is useful to quantify the convexity of the waterfall face. Due to the rugged topography of the spring branch canyon environment, traditional techniques, such as pin-flag and tape measurements are not practical and even dangerous. The waterfall faces are often greater than 3 meters high, steep, and algae covered. The spring branch canyon walls are also steep with actively creeping scree slopes along the bases. Therefore, due to this topography there is no easy way to access the waterfall faces for accurate measurements. The measurement problem was overcome by using a hand-held laser meter mounted on a tripod. A baseline was established below the waterfall face. The length of the baseline was measured using the hand-held laser meter. Measurements were taken on distinct features across the waterfall face and sidewalls from both endpoints of the baseline. The angle of the laser off the baseline and off the horizontal were measured using a compass with mirror. With these measurements, the waterfall faces profile relative to the baseline was reconstructed. A hand-held laser meter is an important tool for measuring waterfalls and other geomorphic features in hazardous environments because measurements can be taken from a safe location. It is possible for one person to take accurate measurements. New baselines can readily be established to measure relative erosion along the waterfall face over time.

H52A-1143 1330h POSTER

The Origin of Convex Waterfalls Along the Niobrara River by Valentine, Nebraska

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Waterfalls on tributaries along a stretch of the Niobrara River east of Valentine, Nebraska have a convex-downstream geometry in the horizontal plane and an arc in the vertical plane. Siltstone forming the cliff face is only slightly indurated and should be easily eroded by stream water. This is not the case as the cliff face on either side of the waterfalls clearly undergoes more rapid erosion than the face of the falls forming a convex geometry. This differential erosion rate includes points where waterfalls occur immediately along the banks of the Niobrara River. At these points, riverbank erosion is clearly more effective upstream and downstream of a waterfall as evidenced by the protrusion of the waterfall face into the river. There appears to be repetitive-cycles of waterfall evolution along the tributaries. The convexity increases until collapse occurs on the face of the falls, headward erosion then occurs, followed by the development of a new convex waterfall. The waterfalls have a more typical geometry (convex upstream) on tributaries in the lower reaches of the Niobrara River, where cliff faces become coarser grained. The tributaries are fed by springs. Several processes interact to form the convex geometry. Freeze/thaw erosion is more effective on either side of the waterfalls. Water enters the face of the falls and wicks into the cliff causing negative pore pressures. Clay coatings on mineral grains appear to play a role in protection from erosion. Algae and lichen growth aids in protecting the face of the falls. Small groundwater flow systems, represented by seepage into the streambed above the falls and discharge to the side of the falls can cause seepage erosion and enhancement of freeze/thaw erosion.

H52A-1144 1330h POSTER

An Empirical Test of the Stream Power Law in Appalachian Plateau Fluviokarst

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Large caves on tributaries of the Upper Cumberland River, Tennessee, USA, record a wave of rapid river incision that advanced up the drainage basin in the Pliocene and Early Pleistocene. We model the passage of a knickpoint in this system as a perturbation to steady-state incision according to a simple stream power law, and test this model against dated river incision events at 7 caves. Model results suggest that values for the drainage-area exponent m are several times higher than those of previous studies. The upstream reaches of the study area are classified as fluviokarst, which is topography formed by the combination of fluvial and karst processes in areas where both soluble and insoluble rocks outcrop in the same drainage basin. In the upstream reaches of the Caney Fork and Obey River, surface drainage is generally interrupted due to diversion into the underlying karst aquifer. Base flow is entirely transmitted through the karst aquifer; the surface channel is occupied only during floods, which occur a few days or weeks each year. This exceptionally flashy discharge varies more strongly with drainage area than in non-karst watersheds, suggesting that values for m should be larger in fluviokarst settings.

H52A-1145 1330h POSTER

Downstream Hydraulic Geometry of Mountain Rivers

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The concept of downstream hydraulic geometry (DHG) was developed for fully alluvial rivers that are presumed to be capable of continually adjusting their dimensions to changes in bankfull discharge. Mountain rivers, although mostly formed in alluvium, may behave differently because discharges along the channel lack the competence to move coarse clasts introduced from colluvial processes or glaciation, or because discontinuous bedrock exposures limit channel adjustment. Consequently, the DHG of mountain rivers could reflect bankfull flows; larger magnitude, less frequent flows; or non-fluvial processes such as debris flows. The research summarized here was designed to test whether traditional DHG concepts apply to mountain rivers, and to determine when correlations between velocity, flow depth, or width, and bankfull discharge, are strongly developed. Rivers with strongly developed DHG are defined here as those with r2 values > 0.5 for at least two of the correlations. I hypothesize that a quantifiable threshold separates mountain rivers with well-developed DHG from those with poorly-developed DHG. This threshold can be expressed using a ratio of hydraulic driving forces to substrate resisting forces. As the ratio increases, the ability of bankfull flows to adjust channel dimensions should also increase. The hypothesis was tested using 8 datasets from mountain rivers in Alaska, Montana, Colorado, Panama, Nepal, and New Zealand. A ratio of either total stream power/D84, or unit stream power/D84, separates rivers with and without well-developed DHG. This approach is a simplification which ignores the presence of bedrock; the duration and frequency of flows as these affect stream power; and non-fluvial processes. However, the results suggest that mountain rivers with greater hydraulic driving forces are more likely to behave like fully alluvial rivers in terms of having well-developed DHG relations.

H52A-1146 1330h POSTER

Applications of Physical Modeling to the Evolution of Slot Canyon Morphology

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Abrasion-dominated fluvial erosion generates slot canyons with intricately undulating wall morphology. Flows in slot canyons are unique in that the walls comprise a significant portion of the wetted perimeter of the flow. Wire Pass, UT incises through massive cross-bedded Navajo Sandstone. The canyon ranges in width from <1 m to ~ 5 m in the slotted sections, and in depth from ~ 5 m to ~ 25 m. Incision in Wire Pass and related slots is limited to ephemeral flash floods; paleoflood debris indicates that the depth-to-width ratios of these flows are at least 1:1. Sub-meter resolution field mapping of a 20 m length of Wire Pass shows that the wall morphology is a complicated combination of both in-phase (meander-like), and out-of-phase (pinch and swell) type undulations. In order to understand the evolution of slot canyon wallforms, and the influence of these shapes on flow dynamics, we recorded the evolution of four distinct canyon wall morphologies in a 2.4 m flume box at the St. Anthony Falls Laboratory. In a substrate consisting of approximately 3:2 mixtures of F110 sand and plaster of Paris, we molded in-phase and out-of-phase undulations, and wide (6.5 cm) and narrow (4 cm) straight initial wall profiles. Sediment-laden water flowed through each canyon at discharges ranging from 2.6 L/s to 4.2 L/s. We made velocity measurements in three dimensions in sections of each canyon. At 5 hr intervals we documented wall and bed morphology at 0.5 cm resolution using a Keyance LK-500 laser mounted on a moving cart. Initial results show that wall faces in both undulating canyons evolve at different rates, and their flow fields are strongly asymmetric. Upstream-facing walls in undulating canyons eroded most rapidly. In the straight-walled canyons, small perturbations developed in the walls. Each canyon incised downward and headward from a knickpoint generated by a consistent lower boundary. Incision depths averaged ~ 6 cm. Incision generally propagated around small cracks in the substrate and in potholes formed around small pebbles. The location and shape of scallops on the bed of each canyon was strongly controlled by wall morphology. Continued analysis of slot canyon dynamics in the field and laboratory should further the understanding of bedrock canyons dominated by abrasion.

H52A-1147 1330h POSTER

Bedrock and Sediment Controls on Channel Morphology in the Henry Mountains, Utah

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Mixed bedrock-alluvial channels on and around the Henry Mountains and Navajo Mountain, southeast Utah, are ideal for unraveling the interconnected controls of sediment flux and bedrock properties on fluvial incision into bedrock because (1) channels incise through a range of lithologies with widely varying physical properties, and (2) sediment types vary systematically and predictably in different channels, with extreme differences in the durability and size distribution of sediment. Tertiary intrusive rocks (diorite) form the cores of the Henry Mountains and sedimentary units surround the central peaks, primarily alternating between sandstones and shales. Channels that tap into diorite at the peaks of the Henry Mountains tend to have smoothly concave profiles, and sediment in these channels has a strongly bimodal distribution, consisting primarily of quartz sand and large diorite clasts. The observed size distribution is caused by the dramatic difference in durability between the igneous intrusive rocks and the surrounding sedimentary units. In contrast, Navajo Mountain exposes the same sedimentary sequence but has no exposed intrusive rock, and therefore no source for durable diorite sediment. Channels on both the Henry Mountains and Navajo Mountain that do not source igneous intrusives but only cut into sedimentary units have more variable channel profiles, with steps and slope changes that often correlate with mapped geologic units, and these channels transport sand and sandstone clasts. DEM and remote sensing analysis and qualitative field observations suggest that systematic variations in slope-area scaling and channel morphology (slope, width, percent rock exposure, erosional bed forms, roughness) occur as functions of substrate lithology and diorite sediment supply. The tools and cover theory of sediment supply and bedrock erosion, first hypothesized by Grove Karl Gilbert in his report *Geology of the Henry Mountains* and recently explored experimentally and theoretically by other researchers, may be the channel-scale mechanism that causes the observed rougher and smoother longitudinal profiles. In some places, high channel slopes over resistant bedrock lithologies in channels with little diorite sediment may represent less efficient local erosion due to a lack of large and durable diorite clasts (one aspect of the tools effect). Conversely, the cover effect is seen where channel slopes appear to be set by the need to transport coarse diorite sediment, as slopes are often significantly steeper over diorite clast-laden reaches than over bare bedrock or sand-laden reaches. Further research may allow the evaluation and refinement of specific erosion models, in particular focusing on ways that variable bedrock lithology affects sedimentation, channel incision and landscape response.

H52A-1148 1330h POSTER

Pool Formation in Boulder-Bed Streams: Implications From 1-D and 2-D Numerical Modeling

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In mountain rivers of Southern California, boulder-large roughness elements strongly influence flow hydraulics and pool formation and maintenance. In these systems, boulders appear to control the stream morphology by converging flow and producing deep pools during channel forming discharges. Our research goal is to develop quantitative relationships between boulder roughness elements, temporal patterns of scour and fill, and geomorphic processes that are important in producing pool habitat. The longitudinal distribution of shear stress, unit stream power and velocity were estimated along a 48 m reach on Rattlesnake Creek, using the HEC-RAS v 3.0 and River 2-D numerical models. The reach has an average slope of 0.02 and consists of a pool-riffle sequence with a large boulder constriction directly above the pool. Model runs were performed for a range of stream discharges to test if scour and fill thresholds for pool and riffle environments could be identified. Results from the HEC-RAS simulations identified that thresholds in shear stress, unit stream power and mean velocity occur above a discharge of 5.0 cms. Results from the one-dimensional analysis suggest that the reversal in competency is likely due to changes in cross-sectional width at varying flows. River 2-D predictions indicated that strong transverse velocity gradients were present through the pool at higher modeled discharges. At a flow of 0.5 cms (roughly 1/10th bankfull discharge), velocities are estimated at 0.6 m/s and 1.3 m/s for the pool and riffle, respectively. During discharges of 5.15 cms (approximate bankfull discharge), the maximum velocity in the pool center increased to nearly 3.0 m/s, while the maximum velocity over the riffle is estimated at approximately 2.5 cms. These results are consistent with those predicted by HEC-RAS, though the reversal appears to be limited to a narrow jet that occurs through the pool head and pool center. Model predictions suggest that the velocity reversal is produced by a boulder-bedrock constriction that rapidly decreases the channel width above the pool by roughly 25 percent. The width constriction creates highly turbulent flow capable of scouring bed material through the pool. The high velocity core that is produced through the pool center appears to be enhanced by the formation of a large eddy directly below the boulder. Values of unit stream power and shear stress indicate that the pool exit is an area of deposition of bed material due to a decrease in tractive force. The presence of a strong transverse velocity gradient suggests that only a portion of the flow is responsible for scouring bed material. After we eliminate the dead water zone, the lowest five percent of the velocity range, patterns of effective width between pools and riffles begin to emerge. The ratio of flow width between adjacent pools and riffles is one measure of flow convergence. At a discharge of 0.5 cms, the ratio of effective width between pools and riffles is roughly 1:1, implying that there is uniform flow with little flow

convergence. At a discharge of 5.15 cms the width ratio between the pool and riffle is about 1:3, demonstrating the strong convergent flow patterns at the pool head. The observed effective width relationship suggests that when considering restoration designs, boulders should be placed in areas that replicate natural convergence and divergence patterns in order to maximize pool area and depth.

H52A-1149 1330h POSTER

Three-Dimensional Hydraulics of Pool-Riffle Sequences in Low-Gradient Streams

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Geomorphologists have long recognized the importance of pools and riffles in the development and maintenance of straight, meandering and braided streams. The ecological importance of pools and riffles has also been acknowledged, with the associated hydraulic variability contributing to the habitat richness required for the development of a healthy ecosystem. Most of the pool-riffle studies to date have concentrated on one or two-dimensions only, sometimes using qualitative information on general flow patterns. Several of these studies have recognized that three-dimensional flow patterns are fundamental to the development and maintenance of pools and riffles and have called for a detailed three-dimensional hydraulic characterization. Laboratory flume experiments were carried out to investigate the three-dimensional flow structure and turbulence characteristics of pools and riffles. The experiments included three different bed configurations: flat bed (FB), centred pools and riffles (CPR), and alternate pools and riffles (APR). The CPR configuration was included since centred pools minimize the possibility of scour near the banks, and are thus particularly suitable for urban rehabilitation projects where bank erosion is undesirable. The sequence FB-CPR-APR represents not only flows with increased complexity but also steps in the restoration process of a degraded stream. Accordingly, the FB case characterizes the behaviour of the channelized stream with no geomorphological diversity, the CPR experiment describes a rehabilitation alternative with man-made in channel structures and the APR set is representative of more natural conditions. Each series included low and high flow conditions. Flow velocities were measured using an Acoustic Doppler Velocimeter on a very dense transverse grid at several cross sections. The high resolution of the velocity data (both in time and space) allowed for the identification of patterns of flow convergence and divergence, secondary circulation, wall shear stresses and turbulence, specific of each configuration. Implications for sediment transport, bed and bank morphology and aquatic habitat are discussed.

H52A-1150 1330h POSTER

Constraining Depositional Slope From Sedimentary Structures in Sandy Braided Streams

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Determination of paleoslopes in ancient fluvial systems has potentially broad application to quantitatively constraining the history of tectonics and paleoclimate in continental sequences. Our method for calculating paleoslopes for sandy braided streams is based upon a simple physical model that establishes depositional skin-frictional shear stresses from assemblages of sedimentary structures and their associated grain size distributions. The addition of a skin-frictional shear stress, with a geometrically determined form-drag shear stress results in a total boundary shear stress which is directly related to water-surface slope averaged over an appropriate spatial scale. In order to apply this model to ancient fluvial systems, it is necessary to measure the following: coarsest suspended sediment size, finest grain size carried in bed load, flow depth, dune height, and dune length. In the rock record, suspended load and bed load can be accurately assessed by well-preserved suspended load deposits ("low-energy" ripples) and bed load deposits (dune foresets). This model predicts an average slope for the North Loup River near Taylor, Nebraska (modern case study) of 2.7 x 10^{-3}. The measured reach-averaged water surface slope for the same reach of the river is 1.37 x 10^{-3}. We suggest that it is possible to calculate the depositional slope of a sandy fluvial system by a factor of approximately two. Additionally, preliminary application of this model to the Lower Jurassic Kayenta Formation throughout the Colorado Plateau provides a promising and consistent evaluation of paleoslope in an ancient and well-preserved, sandy braided stream deposit.

H52A-1151 1330h POSTER

Linkages Between Hydraulics, Morphology, and Benthic Communities in High-Gradient Streams

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In order to explore the effects of physical processes on benthic communities in mountain stream channels, field surveys of stream hydraulics and channel morphology were completed in fifteen stream reaches in the upper East River basin, Colorado. Biological data on macroinvertebrate abundance, life history, mortality, and drift rates have been collected in these streams as part of a multi-year study of mayfly population dynamics, grazer-algal interactions, and predator-prey interactions. The present study entailed collection of data on channel geometry and gradient, grain sizes, and flow characteristics to provide a basis for examining the role of shear stress, stream power, and other physical variables on ecological processes. The study streams had bed gradients ranging from 0.018 to 0.11 m/m and were mostly characterized by step-pool or step-riffle morphology. Seven reaches with fish and eight fishless reaches were surveyed; presence or absence of fish has been found to strongly affect benthic macroinvertebrate dynamics in the study streams. Streams lacking fish tended to have smaller drainage areas, steeper gradients, greater flow resistance (higher Darcy-Weisbach friction factors), and lower discharges than streams with fish, although boundary shear stresses did not significantly differ in fish versus fishless streams. Darcy-Weisbach friction factor showed a strong negative correlation with discharge in the study streams, reflecting a shift in the balance between driving and resisting forces as stream size decreases.

H52A-1152 1330h POSTER

Statistical Analysis of Streambed Sediment Grain Size Distributions: Implications for Environmental Management and Regulatory Policy

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The status of fish habitat in cold water streams in western North America has, by most accounts, been degraded significantly by sedimentation. In particular, land management activities induce erosion that contributes excess sand-size and finer sediment to stream systems, which is believed to have caused increases in the proportion of fine sediment in spawning gravels. Many watershed studies and regulatory programs have, drawing on previous scientific investigations, set thresholds for fine sediment concentrations in spawning beds. This study examines data from gravel bed streams collected with a McNeil sampler in northern California (typically 25 kg), as well as bulk sediment samples from the Waipaoa River in New Zealand (typically 50 kg). Confidence intervals for various percentiles of the grain size distributions were computed from these data using a two-stage sampling approach. Accuracy and precision of data from these sampling programs were considered in relation to the biological/regulatory thresholds as well as the effort required to obtain, process and analyze grain size distributions. Typically, very large samples are required to obtain data with high precision, suggesting that in many circumstances, it may be difficult to assess whether regulatory thresholds are exceeded.

H52A-1153 1330h POSTER

Sediment Dynamics and Southern Steelhead Habitat (Oncorhynchus mykiss) in the Matilija Creek Watershed, Southern California

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Matilija Creek, one of two principal forks of the Ventura River, drains 142 km2 in the Transverse Ranges of southern California. Thanks to rapid tectonic uplift and weak clastic rocks, sediment yields exceed 1200 m3/km2 annually. Matilija Dam was built in 1947 with an initial capacity of 8 million m3 and is now nearly full of sediment. The dam is structurally unsafe, blocks anadromous fish migration, and is being considered for removal. The Ventura River has one of the southernmost runs of steelhead trout (Oncorhynchus mykiss), with an average of approximately 2,500 annually migrating up Matilija Creek before the dam was built. The high sediment yields and highly variable flow regime have raised questions about the interactions among high flows, sediment transfer from lower order tributaries to the third order channels used by the fish, and fish life history. Previous studies in Southern California have documented sediment yields (especially following debris flows and fires, and mostly in the San Gabriel Mountains), but the interaction of geomorphic processes and aquatic habitat in this highly episodic environment is not well understood. We used a combination of mapping and survey techniques, sediment traps, grain size analysis, lithologic analysis and scour rods to study intra-annual geomorphic processes and sediment dynamics affecting Southern Steelhead habitat in the Matilija Creek area in 16 study pools over the 2002 and 2003 flow seasons (dry and "normal", respectively) and found little sediment was deposited or scoured from pools. However, other processes not previously recognized significantly affected the steelhead habitat in the study pools including tufa cementation (carbonate deposition) and alder root growth in spawning gravels, as well as seasonal desiccation of some reaches. Removal of Matilija Dam will reopen suitable habitat to steelhead trout, but managers should recognize that habitat quality is likely to vary considerably from year-to-year, especially in response to episodic events.

H

H52A-1154 1330h POSTER

Effects of Discharge on Hyporheic Flow in a Pool-Riffle Channel: Implications for Aquatic Habitat

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The hyporheic zone is a band of saturated sediments that includes the riverbed, banks and the riparian zone. It is a rich habitat for benthic species and fish. The extraordinary variability of flora and fauna that utilize the hyporheic zone make it a crucial component of river ecosystems. We examine how changes in discharge affect downwelling and upwelling of river water through the sediments that comprise the hyporheic zone. These fluxes have multiple effects, bringing high concentrations of dissolved oxygen and other nutrients into the sediments, and at the same time, the sediments and the benthic species living in the streambed filter the water, reducing the biological and chemical loads (BOD, COD, P, C, NO_x, etc.). The extent of this active zone is a function of the local topography and consequent spatial variation in the near-bed pressure distribution that drives subsurface flow. Analytical solutions for the piezometric head distribution, H, over two-dimensional dunes are known and can be expressed as a sinusoidal function, $H = h_m sin(2\pi/\lambda x)$, where the amplitude, h_m, is expressed by $h_m = 0.28U^2/(2g)(\Delta/(0.34d))^a$. H depends on mean flow velocity, U, water depth, d, and dune wavelength, λ , and amplitude Δ. However, this sinusoidal distribution does not hold for pool-riffle morphologies because flow depths are typically shallow relative to bed form size. To explore this issue we coupled a computational fluid dynamics model (FLUENT) with a simple Darcy subsurface flow model to predict pressure distributions and hyporheic flow for two-dimensional pool-riffle morphologies. Results demonstrate that the intensity, shape, and extent of hyporheic flow paths strongly depend on discharge and its influence on the near-bed pressure distribution. We find

that the position of the most intense downwelling moves from the top of the riffle at low discharge to the tail of the pool at high discharge. Our results suggest that aquatic habitat created by topographically-forced hyporheic flow is stage dependent, requiring some degree of organism adaptation. For example, many salmonids preferentially spawn in pool tails where downwelling river water oxygenates buried eggs. Moreover, we find that while the strength and location of downwelling varies with discharge, downwelling persists in pool tails across all discharges examined, suggesting that salmonid spawning may be adapted to both the location and persistence of topographically-forced downwelling. Embryo survival may depend, in part, on selection of persistent sites of downwelling.

H52A-1155 1330h POSTER

Movement of Sediment Associated With Lowered Reservoir Levels in the Rio La Venta Arm of the Presa Netzahualcoyotl, Chiapas, Mexico

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A joint sedimentation study is currently underway at the Netzahualcoyotl reservoir in Chiapas, Mexico, involving the Comision Nacional de Areas Naturales Protegidas (CONANP) of the Secretaria de Medio Ambiente y Recursos Naturales and the USDA Forest Service. The reservoir is adjacent to the Reserva de la Biosfera, Selva El Ocote, administered by CONANP. Ongoing research is intended to provide watershed and reservoir managers with strategies to protect the resources of Rio La Venta canyon. The Rio La Venta arm of the reservoir is incised into karst terrain, with near-vertical limestone walls up to 300 meters high. The canyon is fed by two rivers, Rio La Selva and Rio Negro, and is surrounded by pristine tropical forest. The majority of the clastic sediment (predominantly sand and fine gravel) entering the reservoir originates in the headwaters of the two rivers which are underlain by weathered and dissected granitic terrain. Rapid sedimentation of the partially inundated canyon poses a threat to the aquatic ecosystem, as well as to recreational resources. Longitudinal and transverse profiles were surveyed in the inundated canyon in March of 2002 and repeated in April of 2003 when the reservoir level was 15 meters lower. The 2002 longitudinal profile shows an inflection from a slope of 0.0017 to one of 0.0075 at 7.2 km downstream of the mouth of Rio Negro. In 2003, the two slopes remained the same, but the bed lowered about 5 meters and the inflection point moved downstream about 2.3 km. We calculated that reservoir lowering in 2003 allowed the transport of 2.5 million cubic meters of sand further out into the reservoir. This volume is more than the average annual rate of filling up to the 2002 level since 1984 when sedimentation was not as advanced (De la Fuente et al., 2002), which was calculated disregarding loss of sediment to the main reservoir. Field observations at late dry season low flows in 2003 revealed active transport of sand and pebbles and formation of fresh bars. Transverse profiles showed a flat bed with multiple submerged channels, consistent with high sediment mobility. Sediment stored in exposed bars up to 4 meters in height consisted of light colored sand beds alternating with dark organic-rich silt and clay beds ranging from a few centimeters to 50 cm in thickness. These beds were deposited in fluvial and lacustrine environments respectively. We conclude that: a) Lowering of the reservoir allowed sediment to be transported out of the canyon; b) Long periods of inundation of the canyon allow accumulation of very fine sediment (clay/silt/organic) which may affect fish habitat; c) Sediment accumulation in the canyon appears to be a balance between accumulation at high reservoir levels and removal at lower levels. Continuing research will examine: past reservoir levels; future changes in channel geometry; sediment sources, particularly recently burned areas adjacent to the reservoir; and fish populations and habitat. These studies will improve our understanding of sedimentation patterns and processes and our ability to make management recommendations for Netzahualcoyotl reservoir.

H52A-1156 1330h POSTER

Bedload Transport in Gravel-Bed Streams: Collaborative Field and Flume Research Using Tracer Stones

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Estimates of bedload transport rates in gravel-bed streams are typically derived from empirical formulae or from sampling. A less common, but promising, approach involves the use of tracer stones and the derivation of the bedload transport rate from individual particle displacement history. A combination of field and experimental (flume) work has begun in a collaborative effort to produce, using tracer data, i) a general predictive formulation for streamwise tracer movement (the longitudinal displacement problem), and ii) a probabilistic form of the Exner equation for sediment continuity and bed elevation fluctuations involving erosion and deposition functions (the vertical mixing problem). We are conducting field and flume studies to identify a relationship between the measured horizontal displacement of tracer stones and the associated excess shear stress over a small increment of time, and to predict the vertical sorting of the sediment among the bed, and the influence of this on the bedload transport rate. Two sediment-recirculation flumes 0.50-m wide and 9-m and 27-m in length have been set up at St. Anthony Falls Lab for this purpose. In addition, two streams with flume-like reaches of adequate length have been selected in western Washington. We present preliminary results that illustrate the types of sampling problems that this research is investigating, and raise fundamental questions that remain to be addressed more thoroughly in a coupled field and flume study than has occurred to date. To these ends, painted tracers stones (magnetized for field purposes) will be tracked in terms of their horizontal and vertical displacement in the field and flume. While sonar will be used in the lab, scour monitors will be used in the field to obtain a predictor of the probability density function for the bed elevation fluctuations.

H52A-1157 1330h POSTER

One-Dimensional Sediment Transport and Turbulence

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The goal of this research is to incorporate the influence of turbulence into an existing one-dimensional sediment transport model. Typically sediment transport models evaluate transport under mean flow conditions. Here, a new model formulation that accounts for turbulence will be developed. The results from an experimental flume study will be used to evaluate and compare the results of the traditional model and the model that incorporates turbulence. The flume experiments are being conducted in a research quality sediment transport flume, capable of simulation of open channel flows and sediment, at Humboldt State University. The one-dimensional average flow method utilizes the average longitudinal flow velocity to determine the sediment transport threshold condition and overall transport. The turbulent method utilizes current research results regarding eddy structure and turbulent velocity fluctuations. The eddy structure, which is cyclic in nature, contains four events (sweeps, ejections and inward and outward interactions) defined by the longitudinal and vertical velocity fluctuations. Recent research indicates that the longitudinal normal stress is the most dominant in particle entrainment. Thus, if the events that make up an eddy are considered as separate cells, an initial eddy structure is assumed, an estimate of the turbulent longitudinal velocity determined, and the rolling eddies are followed through the model, it may be possible to simulate the cyclic process. The fluctuating longitudinal velocity within each cell is determined at random from a Gaussian distribution. Given the time-averaged velocity from the flow model, the instantaneous longitudinal velocity is estimated as a sum of this average and the fluctuating component. If this velocity meets a threshold criterion then sediment transport within the cell will occur. The amount moved will be determined using an empirical sediment relation and will depend on the time associated with the fluctuation and the size of the cell associated with the turbulent event. A one-dimensional model that incorporates turbulence in this way may be useful in understanding the role of turbulence on sediment transport.

H52A-1158 1330h POSTER

Development of a Sediment Transport Component for DHSVM

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The effect of forest management and disturbance on aquatic resources is a problem of considerable, contemporary, scientific and public concern in the West. Sediment generation is one of the factors linking land surface conditions with aquatic systems, with implications for fisheries protection and enhancement. Better predictive techniques that allow assessment of the effects of fire and logging, in particular, on sediment transport could help to provide a more scientific basis for the management of forests in the West. We describe the development of a sediment transport component for the Distributed Hydrology Soil Vegetation Model (DHSVM), a spatially distributed hydrologic model that was developed specifically for assessment of the hydrologic consequences of forest management. The sediment transport module extends the hydrologic dynamics of DHSVM to predict sediment generation in response to dynamic meteorological inputs and hydrologic conditions via mass wasting and surface erosion from forest roads and hillslopes. The mass wasting component builds on existing stochastic slope stability models, by incorporating distributed basin hydrology (from DHSVM), and post-failure, rule-based redistribution of sediment downslope. The stochastic nature of the mass wasting component allows specification of probability distributions that describe the spatial variability of soil and vegetation characteristics used in the infinite slope model. The forest roads and hillslope surface erosion algorithms account for erosion from rain drop impact and overland erosion. A simple routing scheme is used to transport eroded sediment from mass wasting and forest roads surface erosion that reaches the channel system to the basin outlet. A sensitivity analysis of the model input parameters and forest cover conditions is described for the Little Wenatchee River basin in the northeastern Washington Cascades.

H52A-1159 1330h POSTER

Channel Incision and Suspended Sediment Delivery at Caspar Creek, Mendocino County, California.

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Tributary and headwater valleys in the Caspar Creek watershed, in coastal Mendocino County, California, show signs of incision along much of their lengths. An episode of incision followed initial-entry logging which took place between 1860 and 1906. Another episode of incision cut into skid-trails created for

second-entry logging in the 1970's. Gullies resulting from both of these episodes of incision are sensitive to hydrologic fluctuations and feature active headcuts, deepening plungepools, and unstable banks, which continue to contribute sediment to the Caspar Creek channel network. Headcuts are numerous in each channel. In some cases headcuts define the upstream extent of an incised reach; in many cases headcuts migrate up previously incised reaches, increasing the depth of incision. Surveys indicate that bank retreat, plunge pool deepening, and headcut retreat all contributed sediment to the channels between 2000 and 2003. Since bank walls have considerably more surface area than headwalls per given length of channel, and headcuts have largely migrated into positions temporarily constrained by resistant lips, bankwall retreat appears to be a more significant chronic source of sediment than headwall retreat. Stream gage records show that some channels consistently deliver higher levels of suspended sediment than others. In comparing channels, ongoing levels of suspended sediment delivery correlate well with total amount of exposed channel bank (depth of incision integrated over length of channel) in the reaches upstream of stream gages. On an annual to decadal timescale, rates of suspended sediment delivery per unit area of catchment correlate better with the amount of exposed bank area in reaches upstream of stream gages, than with the volume of sediment delivered by landslide events, with total catchment area, or with peak storm flow per unit area. The correlation between amount of exposed bank area and ongoing levels of suspended sediment delivery is attributable to the importance of bank erosion as a sediment source to these gullied channels.

H52A-1160 1330h POSTER

Variability of Reference Shear Stress in Gravel-Bed Streams

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The prediction of sediment transport in gravel bed streams is complicated by heterogeneous bed material and armoring of the bed surface, thus affecting both the availability and mobility of grains on the bed. The application of standard bed-load transport formulae in high gradient, coarse-bedded streams may produce inaccurate results, related to difficulty in defining the critical shear stress for sediment motion (τ_c) as well as in estimating the shear stress available for sediment transport (skin friction). Failure of transport functions to match existing bed-load data sets is related to problems in defining these two parameters. The present study examines possible sources of variation in the reference shear stress (τ_{ref}) using coupled measurements of flow and bed load transport in more than 30 gravel-bed streams and rivers. The study streams encompass a wide range in bankfull discharge (1-650 cms), slope (0.2-5%), and median surface grain size (0.027-0.21 m). Dimensionless sediment transport rates, W^*, were calculated for the bed-load measurements, and then plotted as a function of the reach-average dimensionless shear stress (τ^*). The dimensionless reference shear stress (τ^*_{ref}) was then estimated by selecting the value of τ^* corresponding to a small non-zero transport rate ($W^* = 0.002$). Resulting values of τ^*_{ref} were found to be positively correlated to reach slope, ranging from as little as 0.015 at low-gradient sites to greater than 0.100 at steeper slopes. Bankfull dimensionless shear stress (τ^*_{bf}) likewise increases as slope increases and is highly correlated to τ^*_{ref}, resulting in a consistent ratio of excess shear stress, τ^*_{bf}/τ^*_{ref}, over the range of study sites. These data suggest that the reference shear stress is likely to vary between streams and within drainage basins, especially at slopes greater than 1%, while maintaining a consistent relationship between sediment initiation and bankfull channel morphology.

H52A-1161 1330h POSTER

Timing and Transport of Fine Sediment in the Colorado River

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Gravel-bed reaches of the Colorado River in western Colorado and eastern Utah carry an annual average sediment load of 80-90 tons/km2/yr. Although the river is primarily gravel bed, more than 95 percent of the total sediment load is fine sediment (silt and sand) carried in suspension. This sediment satisfies the traditional definition of wash load, meaning it is not abundant in bulk samples of the bed material taken from low-lying gravel bars, but it is present in different areas of the channel bed characterized by low velocity; these areas include channel margins, secondary channels, or shallow pools, which are common to all reaches. Thus, in any given year, the suspended load carried by the Colorado River reflects varying proportions of sediment supplied from the surrounding watershed and sediment supplied from the channel bed. Analysis of suspended sediment data from USGS gauging stations in the study area indicates that peak sediment concentrations occur on the rising limb of the annual snowmelt hydrograph; the majority of this sediment is silt and clay. As snowmelt discharges increase, the amount of sand in suspension increases, reaching about 30 percent at flows equal to the threshold for bed material (gravel) transport. Sand transport continues after the peak in the hydrograph. The peak in suspended sand concentration occurs, on average, about 2 weeks after the peak in water discharge. At this point in time, suspended sediment concentrations are lower, but the supply of fines is not completely exhausted from the bed. Sediment samples obtained from traps in the riverbed indicate that fine-medium sand (0.25-0.5 mm) continues moving as bed load several weeks after the peak in the hydrograph. The sand fraction of the total load is thus not easily distinguished as wash load or bed-material load. Efforts to improve habitats for endangered fishes in the Colorado River through coordinated reservoir operations must therefore take into account the potential ecological effects of the supply and movement of fines both before and after the peak in the annual hydrograph.

URL: http://www.colorado.edu/geography/geomorph/usfws.html

H52A-1162 1330h POSTER

Preliminary analysis of water discharge and suspended sediment data from the Columbia River Basin: shifting rating curves and diminishing sediment loads

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Significant erosion along the coastlines of southwestern Washington in the last decade has motivated increased studies of sediment sources, sinks, and transport dynamics in the region. A key question is whether a reduction in sediment supply is responsible for the recent shift from a depositional regime. Because the Columbia River is the major fluvial system in the littoral cell, it is important to quantify sediment flux from the Columbia River to the coastal environment. We examine historical records of water discharge and suspended sediment transport along the Columbia main stem and in three subbasins in an attempt to quantify changes in total sediment transport and total load, and examine possible shifts in sediment sources over time. Suspended sediment data from the main stem near Vancouver, WA demonstrate a 3 to 5 fold downward shift in the rating curve in the last 90 years. The same trend is visible in data from the Snake River, with a decrease of almost an order of magnitude in sediment transport since the 1950's. Grain size data from the Kootenai River show a clear fining trend in the suspended load. The John Day River is the only long-term record we examined with no change in the rating curve over time; it is also the largest undammed river in the basin. Calculations of sediment load in the main stem were made using actual water discharge, estimated discharge (assuming no dams), and calculated virgin' flow (Naik and Jay, in review). Preliminary results suggest that changes in the hydrograph (assuming a uniform rating curve) would diminish sediment transport to the coast by up to 20% over the last century; changes in the rating curve are responsible for at least that change, possibly more.

H52A-1163 1330h POSTER

Evaluation of a Laser-Acoustic System for Continuously Monitoring Suspended-Sediment Concentration and Grain Size in the Colorado River in Grand Canyon

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Sandbars and other sandy deposits in and along the Colorado River in Grand Canyon National Park (GCNP) were an integral part of the pre-dam riverscape, and are important for habitat, protecting archeological sites, and recreation. These deposits have eroded substantially following the 1963 closure of Glen Canyon Dam that reduced the supply of sand at the upstream boundary of GCNP by about 94%; sandbars in the upstream portion of Grand Canyon have decreased in size by about 25% during only the last 15 years. Recent work has shown that sand transport in the post-dam river is supply limited, and is equally regulated by the discharge of water and short-term changes in the grain size of sand available for transport. During and following tributary floods, fine sand supplied to the Colorado River travels downstream as an elongating sediment wave. As the front of a sediment wave passes a given location, sand on the bed first fines and sand-transport rates increase independently of the discharge of water. Subsequently, the bed is winnowed and sand-transport rates decrease independently of discharge. By virtue of this process, sand supplied by tributaries is typically exported from the upstream portion of Grand Canyon within months under normal dam releases. Thus, newly input sand may be available to rebuild sandbars during controlled floods conducted only following large tributary floods. Accurate monitoring of sand transport in such a river requires frequent measurements of suspended-sediment concentration and grain size, and cannot be accomplished by using stable sediment-rating curves constructed from a sparser dataset of suspended-sediment measurements. To monitor sediment transport in the Colorado River, we have designed and are evaluating a laser-acoustic system for measuring the concentration and grain size of suspended sediment every 15 minutes. This system consists of (1) a subaqueously deployed laser-diffraction instrument (either a LISST 100 or a LISST 25X) connected to an automatic pump sampler, and (2) an acoustic-doppler current meter. When laser transmission drops below a user-defined threshold (as a result of increased suspended-sediment concentrations), the LISST triggers the automatic pump sampler to collect samples at a user-defined rate. This allows samples to be collected when the suspended-sediment concentrations exceed the upper limit for the LISST and the acoustic-doppler current meter (around 2000-3000 mg/l). Beginning in August 2002, we began testing this system at 4 locations along the Colorado River in Grand Canyon, and have developed stable box coefficients relating the pump, laser-diffraction, and acoustic-backscatter point measurements to cross-sectionally integrated measurements of suspended-sediment concentration and grain size. Variability between either sequential laser-diffraction or acoustic-backscatter measurements is substantially less than the variability between sequential cross-sectionally integrated measurements of concentration and grain size (collected with standard USGS samplers and methods). Furthermore, the variability between either the laser-diffraction or acoustic-backscatter point measurements and the cross-sectionally integrated measurements is typically less than the variability between paired cross-sectionally integrated measurements of concentration and grain size. These observations suggest that more error is introduced during the computation of suspended-sediment loads based on conventional sampling methods than is introduced during the computation of suspended-sediment loads using the laser-acoustic system.

H52A-1164 1330h POSTER

The Mechanism of Water and Sediment Discharges From a Glacier, Based on the Separation by the AR Method

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The dynamics of water and sediment discharges from Gulkana Glacier, Alaska was examined by analyzing their hourly time series observed in a proglacial river in the glacier-melt season of 2001. The data plots on semi-log paper for recessive part of water and sediment discharges indicate that each of water discharge and sediment discharge consists of "fast" and "slow" components. The fast component probably corresponds to an englacial and subglacial, "channelized" drainage system downstream of snow line in the ablation area, while the slow component is related to a subglacial, "distributed" drainage system upstream of snow line. The hydrological and meteorological observations indicated that suspended sediment concentration (SSC) and water discharge both increased abruptly in ca. 2 days after the maximum air temperature was recorded. Such an event would occur by a change of the subglacial drainage system from "distributed" to "channelized". This event probably results from the great erosion of subglacial sediment by the collapse of linked cavities in the distributed drainage system. Flow separation by the AR method, using a numerical filter, was performed for hourly time series of water and sediment discharges. As a result, for the slow component, there existed the high linearity between SSC (mg/l) and water discharge (m3/s) on log-log paper.

H

H52A-1165 1330h POSTER

Interpretation of fine and coarse sediment yield from Bench Glacier, Alaska

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Quantifying the rate of bedrock erosion by glaciers is crucial to our understanding of alpine landscape evolution. We document basin-averaged sediment evacuation for three summers at the 7-km-long Bench Glacier, Alaska, based on 15-minute gaging of stream stage and turbidity, together with manual sampling of sediment concentrations and bedload transport in the exit stream. Sediment evacuation was equivalent to 1-2 mm/yr of bed lowering each summer, with bedload accounting for 30% of the total output. Simultaneous time-series of ice surface displacements each summer yielded consistent basal sliding of only 1-2 m/yr. The ratio of bed-lowering to sliding is 10^{-3}, an order of magnitude higher than found by Humphrey and Raymond (1994). A simple interpretation of glacier sediment yields is confounded by unknown changes in subglacial sediment storage. We consistently observed a decline of the sediment discharge over the summer for a given water discharge, indicating seasonal sediment exhaustion within the subglacial channelized network. Does this reflect complete removal of stored sediment from the entire glacier bed? High-resolution GPS measurements at several locations in the ablation zone show episodic surface ice trajectories that can best be explained by sliding on up-glacier inclined bedrock ledges during rapid motion events. We therefore infer that a large portion of the bed in the ablation zone is sediment free. However, sediment may be retained in the accumulation zone, possibly because the subglacial channelized network does not extend this far upglacier. We suggest that efficient removal of sediment from the ablation zone may enhance erosion by increasing ice-bedrock contact, whereas basal sediment storage within the accumulation zone may inhibit bedrock erosion. We therefore predict that over long timescales, bedrock steps should form near the upglacier extent of the channelized network.

H52A-1166 1330h POSTER

Rates and Form of Fluvial-System Response to Climate Variability Over Decadal to Holocene Timescales - Cuyama Valley, California

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Fluvial-system response to climatic perturbation over multiple timescales is well-preserved in Cuyama Valley, southern California. Here we present analysis of rates and forms of 1) aggradation, 2) incision, and 3) lateral erosion over decadal to Holocene timescales. After deposition of a >12m thick alluvial unit (P-H) (dated at 10,800 ^{14}C yrs BP) at the Pleistocene-Holocene climatic transition, the Cuyama River incised and eroded laterally, removing the P-H fill from all but the widest reach of the Cuyama Valley. Alluvium from between 10,000 ^{14}C yrs BP and 2,000 ^{14}C yrs BP has not been observed in the main valley. If aggradation did occur during this time it was subsequently removed by incision and lateral erosion. 9-12m of aggradation has occurred since 2,000 ^{14}C yrs BP along a 35km reach. Aggradation initiated before 1691 ^{14}C yrs BP, which corresponds to a wet-dry climatic transition recorded at nearby Soda Lake after 2100 cal yrs BP Subsequently, at least one episode of floodplain degradation punctuated an overall aggradational regime that continued until recent arroyo cutting initiated in the downstream reaches. A minimum age estimate for the initiation of arroyo cutting is 469 ^{14}C yrs BP Incision has propagated upstream at an average rate of 100m/yr. Anecdotal evidence indicates that the Cuyama River reached its base level of erosion (indicated by exposed bedrock channel-bed) only within the last century. The dominant mode of the fluvial system at present is lateral erosion. GIS analysis of remote sensing data capture patterns of lateral erosion that have occurred between 1989 and 2002 removing up to 100m of bank material in localized areas. Analysis of streamflow data indicate that this erosion was dominantly a result of El Niño flooding in February of 1998, a 25-yr flood event that resulted in loss of human life and agricultural land in Cuyama Valley. Response of the fluvial system to well-constrained triggers appears generally well-preserved in the stratigraphy and morphology of Cuyama Valley. However, these results also indicate that the timescale for preservation of sedimentary fill in a topographically confined axial system may be on the order of only a few millennia, and gaps in a preserved alluvial sequence do not necessarily indicate lack of response to perturbation.

H52A-1167 1330h POSTER

Historical Channel Change on the Upper Gila River, Arizona and New Mexico in Response to Anthropogenic Modifications and Extreme Floods

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Over the past century, the majority of alluvial reaches along the upper Gila River in Arizona and New Mexico have been leveed in an attempt to protect adjacent property from flood damage. In addition, the demand for irrigation has prompted the construction of diversion dams in these alluvial reaches to divert water for agriculture. Detailed geomorphic mapping and investigation of historical channel change along the upper Gila River reveals that many channel modifications are catalysts for major channel change and can result in catastrophic property loss rather than safeguarding valuable farmland. Channel widths were measured every kilometer for approximately 160 km from Safford Valley, Arizona through Cliff-Gila Valley, New Mexico for eight decades to develop a quantitative analysis of channel change. An overall pattern of channel narrowing and widening coincides with periods of few large floods and periods of multiple large floods, respectively. Furthermore, reaches along the upper Gila River with greater channel modifications have experienced more variation in channel width than reaches with fewer modifications. Although the average width of the upper Gila River is very similar to the width of the 1935 channel, the lateral position of the channel is very different in many reaches. Many channel changes in recent decades are unprecedented in previous historical aerial photography and reveal that the upper Gila River is currently eroding stream banks that are several hundred years to thousands of years old. These changes are consistently associated with artificial channel constrictions, such as levees, bank protection, and bridges, that have been built and rebuilt following large floods and that have accelerated natural channel narrowing during periods of few large floods. Examples of geomorphic responses due to channel modifications along the upper Gila River include lateral erosion upstream of levees and diversion dams, redirection of flow over diversion dams into opposite banks, breaching of levees during floods and resultant erosion behind levees, channel widening downstream of levees, aggradation in leveed reaches, and lateral migration associated with straightened tributary channels.

H52A-1168 1330h POSTER

The Effects of Dams on Downstream Channel Characteristics in Pennsylvania and Maryland: Assessing the Potential Consequences of Dam Removal

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The potential downstream effects of dam removal were assessed on fifteen sites of varying dam size and characteristics in Pennsylvania and Maryland. The dams ranged in size from a 30 cm high fish weir to a water supply dam 57 m high. Stream order ranged from 1 to 4. The dams are located in watersheds with varying degrees of human disturbance and urbanization. The dams are also operated differently, with significant consequences for hydraulic residence time and downstream flow variability. Most streams were alluvial, but 6 of the reaches were clearly bedrock channels. We hypothesize that the channel upstream, which is unaffected by the dam, will provide an accurate model for the channel downstream of the dam long after dam removal. Therefore, reaches upstream and downstream of the dam were compared to determine the effects of the dam as well as the condition of the stream that will ultimately develop decades after dam removal. Surprisingly, the dams had no consistent influence on channel morphology. However, the percentage of sand is significantly lower downstream than upstream: the mean % sand downstream is 11.47%, while the mean % sand upstream is 21.39%. The coarser fractions of the bed, as represented by the 84th percentile grain diameter, are unaffected by the presence of the dam. These results imply that decades after dam removal, the percentage of sand on the bed will increase, but the coarse fraction of the bed will remain relatively unchanged.

H52A-1169 1330h POSTER

Channel Morphology and Sediment Transport Associated with St. John's Dam Removal

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Dam removal has caught the attention of the public and water resource managers as a strategy for river restoration. Flushing of reservoir sediments downstream is one of the primary concerns associated with dam removal. Sediment release modifies downstream and upstream river morphology, and consequently influences flow, fish habitat and ecosystem processes in rivers. In order to fully understand the effects of dam removal on floodplains and channels, it is necessary to understand the associated dynamics of sediment transport. Using the most recent survey techniques, we monitored and recorded the changes in river morphology and sediment distribution resulting from the removal of the St. Johns' dam. Traditional sediment transport models are compared to simulate the dam removal event. A two-fraction sediment transport model is tested using the real time survey data and compared with the model developed using the graded sediment module of MIKE 11 software. This research will provide a valuable reference for water resources managers and decision makers pursuing dam removal and river restoration.

H52A-1170 1330h POSTER

Channel Recovery Following Dam Removal: Lessons From Three Historic Dam Removals of the Middle Atlantic Piedmont

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To determine the rates and processes of channel recovery following dam removal, we studied 3 sites along Muddy Creek in southeastern Pennsylvania. Garthridge Dam, 12.2 m high and located the farthest downstream, was breached in 1933. Highrock Dam, 1.8 m high and located the farthest upstream, was breached in 1972. Castle Fin Dam, 3.1 m high, was removed in 1997. We surveyed the longitudinal profile and channel cross-sections upstream of the former dam site. We also sampled the bed material and mapped floodplain and channel deposits. Undammed reaches far upstream were used as controls. At all sites, laminated muddy reservoir deposits are still preserved as terraces up to 5 m high bordering the channel. These deposits are persistent and will likely remain in place for decades, if not centuries. In addition, these deposits are a preferred habitat for exotic plant species, which had exceptionally high cover values at all three sites. At Castle Fin, laminated muddy reservoir deposits underlie the channel bed, indicating that the channel has not incised to its predam elevation after 5 years. At the other sites, vertical incision has completely removed fine-grained reservoir deposits from beneath the channel. Bed material is finer grained near the former dam site than at the control reaches at all the sites, and the water surface slope is higher near the former dam site than at the control reaches. These data suggest that, even after

many years, channels above locations of removed dams are noticeably different from nearby control reaches, possibly indicating that complete recovery from dam removal is an inherently slow process.

H52A-1171 1330h POSTER

Physically Modeling Stream Channel Adjustment to Woody Riparian Vegetation

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Stream restoration designs often use vegetation to promote bank and channel stability, to facilitate point-bar development, and to encourage natural colonization of riparian species. Here we examine the adjustment of an alluvial channel to in-stream and riparian vegetation using a distorted Froude-scale flume model with a movable boundary. A decimeter-scale trapezoidal channel comprised of 0.8-mm diameter sand was systematically vegetated with emergent, rigid dowels (3-mm in diameter) in rectangular and hemispherical patterns with varying vegetation densities while conserving the shape of the zone and the geometry of the vegetal patterns. Alternate sides of the channel were vegetated at the prescribed spacing of equilibrium alternate bars, ca. 5 to 7 times the channel width. Using flow conditions just below the threshold of sediment motion, flow obstruction, deflection, and acceleration caused bed erosion, bank failure, and morphologic channel adjustments that were wholly attributable to the managed plantings. As vegetation density increased, the magnitude and rate of scaled channel adjustment increased, which included increased channel widths, bankline steepening and meandering, and thalweg meandering. As the modeled channel began to meander, the stream bed aggraded and flow depth decreased markedly, creating a continuously connected, inter-reach complex of mid-channel bars. This study demonstrates the utility of using managed vegetations in stream corridor design and meander development, and it provides the practitioner with guidance on the magnitude of channel adjustment as it relates to vegetation density, shape, and spacing.

H52A-1172 1330h POSTER

Perception of Wood in River Channels

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In managing river channels, wood is often perceived as hazardous and has traditionally been removed. On the other hand, wood provides many benefits including food and habitat for fish and mechanisms for energy dissipation. Increasing recognition of the positive role of wood has encouraged the reintroduction of wood to restore rivers. However, it is not clear how widely this practice is accepted, and whether traditional views of wood hazards may influence the success of such restoration projects. This paper describes a large-scale effort to increase understanding of how wood is perceived in stream channels. This project, led by H. Piegay and K.J. Gregory, involves an international group of workers from 9 countries in contrasting parts of the world. A total of 1886 surveys were given to students 20-25 years of age to test the hypothesis that the perception of wood is related to one's socio-cultural environment. Students were asked to view a set of 20 standard photographs, 10 with wood and 10 without, and to answer a set of questions related to how hazardous the scenes are perceived. Results show clear differences in perception, with students from Texas, USA, viewing streams with wood to be more dangerous, less aesthetic, and to need more improvement than those without. These perceptions contrast with those from the Pacific northwest and some areas around the world, providing clues to the potential success and acceptance of reintroducing wood in stream restoration.

H52A-1173 1330h POSTER

Increasing the Stability of Streambanks through the Hydrologic Effects of Riparian Vegetation: Experimental Results

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Riparian vegetation can provide both mechanical and hydrologic benefits to the shear strength of streambanks. Recent research has shown that the hydrologic effects of water withdrawal on streambank stability can be significant, and far exceeds that provided by root reinforcement during certain times of the year. To accurately quantify the hydrologic effects of riparian vegetation on streambank stability and to determine optimum species for bank stabilization, experiments with common riparian species (planted in 2000) were conducted in large soil monoliths. Pore-water pressure data from depths of 30 and 70 cm within soil monoliths containing Black Willow, River Birch, Eastern Sycamore, and bare soil were monitored for the period February through June, 2002 (Figure XX1). This period was selected because it represents the wettest and, therefore, the most critical period for streambank stability. With rainfall, all of the tensiometers showed decreases in matric suction (negative pore-water pressure) or increases in positive pore-water pressure reflecting the addition of water. However, both the magnitude of the changes and the absoulute values attained within the soil monoliths differed by treatment. At both 30 cm and 70 cm depths, the soil in the control monoliths became the wettest during and after rainfall indicating the role of the woody species in maintaining matric suction and enhancing shear strength. During late February and early March before leaves appeared on stems and branches, there appeared to be little difference in matric suction values between individual species although matirc suction values within these monoliths were still greater than within the control monoliths. This lack of significant differences between the vegetated monoliths and the controls are at least in part a function of the young age of the specimens and the lack of a carryover of high values of matric suction from the previous summer that can be typical in more mature stands of trees. New growth appeared in early April with a theoretical corresponding increase in evapotranspiration. This change is seen as a steepening of the drying trend and a further departure from the control monoliths between precipitation events. The increasing effect of evapotranspiration is seen as the difference in matric suction drying-values and trends at both depths between the control and individual specie monoliths during May and June. Sycamore and River Birch create the largest matric suction values during this period (80 kPa). Over the period of monitoring, River Birch showed the greatest overall effect on matric suction values at both 30 and 70 cm, Black Willow the least. Averaging the difference in matric suction values at the two depths and multiplying this difference by tan ϕ^b provides an indication of the average increase in apparent cohesion that each of the woody species would provide to a hypothetical streambank. Thus, River Birch would provide a 310% increase in apparent cohesion due to matric suction, followed by Sycamore (200%) and Black Willow (100%). These values are significant in light of typical values of effective cohesion in many silt-clay systems.

H52A-1174 1330h POSTER

A new Approach for Quantifying Root-Reinforcement of Streambanks: the RipRoot Model

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Riparian vegetation plays an important role in controlling geotechnical and fluvial processes acting along and within streambanks through the binding effects of roots. Quantification of this mechanical effect is therefore essential to accurately model streambank stability. Until now, most attempts to include the effects of root reinforcement by riparian vegetation have used root-cohesion values estimated using the Wu et al. (1979) equation, requiring the tensile strengths and diameters of the roots crossing the potential shear-plane. However, the Wu et al. equation is a static model that assumes that all roots break, and that they all break simultaneously. Field observations and laboratory experiments have shown that in reality the roots do not all break simultaneously, and that the breaking of roots during mass failure is in fact a dynamic process. Static models such as the Wu et al. equation are therefore likely to produce overestimations of cohesion due to roots. As a response to this concern, a dynamic root reinforcement model (RipRoot) was developed, based on the concepts of fiber bundle models (FBM's) used in materials science. Within the model the root-soil system is loaded incrementally resulting in progressive root breaking and redistribution of stresses from the broken roots to the remaining intact roots in the soil matrix. The redistribution and loading process continues until either all of the roots have broken, or equilibrium is reached where the root network supports the driving force imposed on the bank. The increase in bank cohesion using the static Wu et al. equation are 18% to 38% higher than RipRoot for riparian tree species, including Black Willow, Sandbar Willow, Cottonwood, River Birch and Eastern Sycamore, and 49% higher for Switch Grass. These variations in cohesion values can have a significant impact on streambank Factor of Safety (Fs) values calculated using the Simon et al. (2000) bank-stability model. For example, a 3m high silt streambank had a Fs of 0.98 without vegetation, indicating instability. With the addition of cohesion from 200 River Birch roots this value increased to 1.22 using the RipRoot value (Conditionally Stable) and 1.37 using the Wu et al. equation (Stable). In this example both of the root models produced cohesion values that were large enough to make the bank more stable, but the more conservative value from RipRoot suggests the bank may only be conditionally stable. Results to date indicate that the dynamic nature of RipRoot removes some of the overestimation from the static equation of Wu et al. (1979), therefore producing more realistic values for root reinforcement, which are particularly useful and important in the context of river management and restoration.

H52A-1175 1330h POSTER

Fluvial Bank Erosion in the Meandering River Asker, UK: Insights from Computational Fluid Dynamics (CFD) Modelling

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River bank erosion often significantly contributes to the catchment sediment yield. Knowledge of the rates & controls on bank erosion events is therefore important in understanding sediment flux. In recent years progress has been made in understanding processes controlling large-scale mass failure (MF) of stream banks, but less attention has been paid to the role that direct fluvial erosion (FE) plays in bank retreat. This is an important omission, not only because FE is a significant process in its own right, but because FE also often triggers mass failure. FE models are typically of the form: $E = k(\tau - \tau_c)^b$ where E is the bank erosion rate, τ is the applied fluid shear stress, τ_c is the critical stress for entrainment of the bank material, k is an empirically-derived erodibility parameter, and b is an empirically-derived exponent, often assumed to be close to unity. To apply this model, accurate observations of applied fluid stresses, FE rates & bank erodibility are required. Recent developments in bank erosion monitoring technology [e.g. *Lawler*, 1993], and in the quantification of the bank erodibility parameters k and τ_c using jet-testing devices [e.g. *Hanson and Simon*, 2001; *Dapporto*, 2001], offer the means of determining FE rates and bank erodibility. Nevertheless, the problem of collecting the high-resolution spatially-distributed data needed to characterise near-bank fluid stresses remains. One possible solution is to use Computational Fluid Dynamics (CFD) models as a substitute for empirical data. CFD simulations potentially offer a means of acquiring near-bank, distributed, boundary shear stress data at very high spatial resolution. In contrast, empirical data sets of comparable spatial extent and resolution are very difficult to obtain, particularly during the large (competent) flows of interest here. The critical question is therefore whether CFD-derived data are sufficiently accurate for this purpose. Herein we evaluate a series of 3-dimensional CFD simulations for a (200 m long) meander loop on the River Asker at Bridport in southern England. CFD models under specific steady (peak) flow conditions were developed using FLUENT, with peak flow discharge estimates obtained from an adjacent gauging station. The geometry of each model was specified using DEMs of the channel created from high-resolution tacheometric surveys of the study reach, with water surface elevation defined using a network of crest gauges spaced at 20 m intervals along the reach. Zero slip boundary conditions were defined at all sidewall nodes and initial flow velocity vectors at all nodes at the upstream inlet were estimated with reference to 3D flow velocity data acquired using Acoustic Doppler Velocimetry (ADV) at this location. Simulated flow fields for the extent of the study reach were then evaluated by comparing simulated and observed surface velocity vectors, the latter being derived from Particle Image Velocimetry (PIV), supplemented by ADV data in selected (accessible) locations. Finally, we use the near-bank boundary shear stress data obtained from the CFD models to develop insight into the nature and effectiveness of FE processes within the study reach.

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H52A-1176 1330h POSTER

Influence of the Atchafalaya River on Stratigraphic Evolution of the Chenier Plain Inner Shelf, Northern Gulf of Mexico

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This study provides new constraints on the influence of the Atchafalaya River, a major distributary of the Mississippi River, on stratigraphic evolution of the Northern Gulf of Mexico inner continental shelf. Sedimentary, geochemical, and shallow acoustic data have been used to identify the western limit of the distal Atchafalaya subaqueous delta, and to estimate the proportion of Atchafalaya River sediment that accumulates seaward of Louisiana's chenier plain coast. The results demonstrate a link between facies distribution on the inner shelf and geomorphic variation on the chenier plain. A zone of coastal mudflat progradation corresponds to the location of Atchafalaya sediment accumulation on the inner shelf. West (downdrift) of the subaqueous delta, relict sediment is exposed that was originally deposited between 1200 and 600 years BP during activity of the Lafourche lobe of the Mississippi Delta complex. Mass balance calculations indicate that the eastern chenier plain inner shelf and coastal zone form a sink for 7 +/- 2% of the Atchafalaya River sediment load.

H52A-1177 1330h POSTER

Event-Based Sedimentation in a Flood Bypass: Examples From the Sacramento Valley, California

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Flood bypasses are miniature, anthropogenic analogs of flood basins, which abutted many lowland rivers before the advent of major flood control engineering. Whereas natural lowland floodplains are frequently inundated by diffuse overbank flow or localized crevasse splays, an engineered bypass is only activated when passive weirs near the main channel are overtopped during large floods. Consequently, a bypass represents a focused pathway for the transport of water and sediment that may reflect a legacy of event-based sediment accumulation, compared with the more chronic, diffuse sedimentation across natural flood basins. Our investigations suggest that bypasses are net receivers of suspended sediment from the main channel, with recent sediment accumulation patterns that reflect the dimensions, flow history, and frequency of over-weir sediment delivery. Our preliminary field observations and laboratory measurements indicate that sedimentation in Colusa and Yolo Bypasses may be dominated by a few large sedimentation events (of order $\sim$1 m of deposition per event). However, little is known about how sediment accumulation occurs in bypasses during floods. This study commences a detailed investigation of the links between hydrology and sedimentation in the flood bypasses of the Sacramento Valley. Our strategy is to 1) model the over-weir conveyance and intra-bypass accumulation of fine sediment during floods, and 2) sample, describe, and date these sediment deposits to verify the numerical model. We modeled the influence of the 1964-1965 hydrologic event on sedimentation in the Colusa-Sutter-Yolo Bypass system by combining hydrologic records with empirical models of suspended-sediment concentration and suspendibility calculations. We used records of flood discharge for the event period into and through Colusa, Sutter, and Yolo Bypasses to compute sediment concentration entering the system based on discharge-concentration relationships and simplified hydraulics within the bypass system. We computed daily deposition via suspendibility criterion of various grain sizes at selected loci. The model results are being empirically validated with accumulation thicknesses, textures, and dates derived from ^{210}Pb CIRCAUS geochronology, sediment granulometry, and X-radiographs from 2-6-m-deep vertical cores collected at various locations throughout the bypass system.

H52A-1178 1330h POSTER

Experiments on Sediment Trap Efficiency in Reservoirs

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The results of experiments on sediment trap efficiency in reservoirs are presented. Five different outlet conditions were examined during the experiments. The goal of this research is to obtain the evolution of the trap efficiency in reservoirs as a function of the outlet position. Two different materials, coal slag and glass beads, were used in the experiments to simulate sand and silt in the reservoir. The specific gravities are 2.60 (coal slag) and 2.50 (glass beads). Sand is deposited in the delta region. Silt plunges in the foreset of the delta and forms a turbidity current. The downstream wall of the reservoir forces the turbidity current to undergo a submerged hydraulic jump. A muddy pond with a distinctive turbid-clear water interface is formed downstream of hydraulic jump. Part of the silt is trapped in the reservoir forming a bottomset. The silt that is not retained in the reservoir escapes through the outlet. The results, for this specific set of experiments, indicate the presence of an optimal outlet position for maximum venting capacity (minimum trap efficiency).

H52A-1179 1330h POSTER

Are Lake-connected Streams Different in Ways Other Than the Connection? Implications for Studies of Stream-Lake Interactions in the Sawtooth Mountains, Idaho.

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In mountain landscapes, stream form changes rapidly downstream, though this continuum is modified by local controls such as valley confinement, knickpoints, and lakes. Streams flowing into and out-of lakes may have different geomorphic characteristics than watershed position would predict because lakes attenuate flows and trap transported sediment. Lake inflow and outflow stream geomorphology may also reflect the glacial structuring processes that initially created lakes in mountain regions. We began testing the hypothesis that lakes establish important fluvial geomorphic process domains that influence stream nutrient cycling and groundwater-surface water exchange by characterizing lake inflow and outflow stream and valley geomorphology in the Sawtooth Mountains Lake District in Idaho. We identified 30 paired inflow and outflow reaches, and 30 stream reaches not connected to lakes and quantified their stream and valley form and watershed position from 30 m digital elevation models (DEMs). Multivariate analyses of this data set indicate that while changes along downstream continua dominate, valley width, valley floor width, and longitudinal valley dynamics (widening or narrowing), along with variation in channel slope and drainage area, characterize differences among inflow, outflow, and unconnected stream reaches. Field measurements of 8 stream-lake systems (16 stream reaches) in this data set, including bankfull height and width, sinuosity, channel and valley gradient, bedform, and particle size distributions, were used in mountain stream classification systems. Preliminary results indicate that outflow streams have steeper channel gradients, larger mean bed material, and lower bankfull heights than paired inflow streams and that both inflow and outflow streams may not easily fit into established mountain stream classes. These results are considered in the context of stream hydrologic storage and nutrient cycling processes being concurrently studied in the Sawtooth Mountains.

URL: http://bioweb.usu.edu/biogeochem/SLI/stream-lake_interact.htm

H52A-1180 1330h POSTER

Catastrophic Floods Through the Eastern Outlets of Glacial Lake Agassiz: Drainage Routes and Event Magnitudes

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Glacial Lake Agassiz was the largest lake in North America during the last deglaciation, extending over a total of 1.5 million km^2 before its final drainage at about 7700 ^{14}C yr B.P. Over its 5000-calendar-year history, Lake Agassiz was the source of numerous catastrophic outbursts, the largest of which may have influenced climate in the North Atlantic region by disrupting oceanic thermohaline circulation. New high-resolution paleotopographic reconstructions of the eastern outlets of Lake Agassiz provide a foundation for understanding the complex manner in which terrain morphology controlled the routing of overflow through the eastern outlets during the lake's Nipigon Phase (ca. 9400 - 8000 ^{14}C yr B.P.), and for understanding the causes of outlet-driven declines in lake level during that period. Although flow paths across the divide between the Agassiz and Nipigon basins were numerous, eastward releases from Lake Agassiz to glacial Lake Kelvin (modern Lake Nipigon) were channeled downslope into a relatively small number of major channels that included the valleys of modern Kopka River, Ottertooth Creek, Vale Creek, Whitesand River, Pikitigushi River, and Little Jackfish River. From Lake Kelvin, these waters overflowed into the Superior basin and ultimately flowed into the Atlantic Ocean. The many lowerings in lake level between stages of the Nipigon Phase, controlled by topography and the position of the retreating southern margin of the Laurentide Ice Sheet, had magnitudes of up to 58 m, although some of these drawdowns may have occurred as multiple individual events that could have been as small as several meters. The volumes of water released in association with drops in lake level may have been as great as 8100 km^3, and for all Nipigon stages were probably between about 140 and 250 km^3 per meter of lowering.

H52A-1181 1330h POSTER

River Channel Cut-off Dynamics, Sacramento River, California, USA

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We measured patterns of channel migration and cutoff on a 200 km reach of the central Sacramento River (ranging from Red Bluff to Colusa) over the last century. The river is a meandering alluvial stream which flows along the eastern margin of the Great Central Valley. River bank locations and channel centerlines were mapped from historic topographic maps (1887 and 1904) and aerial photographs (1920 -1997) and stored in a GIS format. By intersecting sequential channel centerlines, we measured changes in river mobility over time, identified approximate dates and locations of cutoffs, and quantified cut-off meander bend morphology. We identified 38 cutoffs over this period of study and compared geometries of cut-off versus stable bends. While 4-7% of the entire channel length migrated via progressive migration and 2-10% tended to migrate via cut-off per year over this period, we found that the majority of lateral channel change was attributable to cut-off processes alone. We also estimated that cutoff frequency tended to increase up to three-fold over time. Further, by plotting cumulative migration over time against a valley axis coordinate system, we noted that highly mobile reaches tend to be separated by relatively static reaches. Over this time scale, we do not observe the classical pattern of downstream migration of meander trains. We explore potential controls on cut-off location including valley slope and tectonics, tributary location, and mapped channel modifications.

By improving our ability to predict the likelihood of meander cut-off, resource managers will be better able to balance habitat restoration with future demands for flood control and water supply

H52A-1182 1330h POSTER

When did the Nile Begin?: Remote Sensing Analysis of Paleo-drainages Near Kom Ombo, Upper Egypt

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The geomorphology of Southern Egypt is dominated by numerous dry riverbeds termed wadis, many of which formed before the modern transcontinental Nile began flowing north. Many of these are relict channels that formed part of an older (Late Miocene) drainage system that flowed westward from the Red Sea Hills and only drained the area of modern Egypt. This older drainage was disrupted and reworked by the modern north-flowing Nile in the mid- to late Pleistocene but is well-preserved in the hyper-arid Sahara and can be studied using remote sensing images. Various optical and radar data along with digital elevation models (DEM) extracted from Shuttle Radar Topography Mission (SRTM) data were used in combination to map and establish the chronological order of different drainage systems and to study the drainage reorganization in southern Egypt. Remote sensing analysis revealed stream capture events in the region around the city of Kom Ombo, on the northern flank of the Nubian Swell. The images show that the older, west-flowing Wadi Abu Suberia has been captured by the north-flowing wadis of Ellawi and Kharit. These streams may owe their aggressive headwater erosion to development of the east-west trending Kom Ombo graben. Analysis of SRTM DEMs shows that the drainages in southern Egypt are dominantly oriented east-west and flow into the Nile. SIR-C radar images reveal that Wadi Kubbaniya, located immediately west and across the Nile from Wadi Abu Suberia and now draining east, was once the downstream section and Wadi Abu Suberia the upstream section of the same river. This W- to NW- flowing drainage has been referred to as the Kubbaniya Nile. The Kubbaniya Nile can be traced on the SIR-C images as far north as the southernmost extent of the Gallaba Gravel Plain where it is lost under Quaternary gravel and sand deposits. Analysis of the present-day drainage using SRTM DEMs suggests that a subtle channel runs north through the Gallaba Plain and joins the Nile channel further upstream. This study indicates important neotectonic movements of the E-W trending Nubian Swell centered on the Egypt-Sudan border during Plio-Pleistocene times caused a massive reorganization of drainages in southern Egypt and allowed the Nile to flow north across the swell. These observations are also important for identifying and exploiting groundwater resources in the region. Ancient paleochannels of the Kubbaniya Nile and other components of the pre-Nile drainage system are promising locations to explore for groundwater. Establishing a chronology for when the east-west trending drainages were disrupted can be used to constrain when the modern, transcontinental Nile began to flow across the Nubian Swell.

H52B MCC: 3024 Friday 1340h

The Influence of Scale on Characterization of Fractured-Rock Aquifers II

Presiding: **W C Burton,** U.S. Geological Survey**;** **A M Shapiro,** U.S. Geological Survey

H52B-01 1340h INVITED

Strategies for Dealing with Scaling Issues in Data Acquisition, Characterization and Numerical Modeling of Fractured Aquifers.

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Fractures and their flow and transport properties scale significantly, in different ways and at different rates. Thus, the importance of a factor at one scale may differ significantly at another scale. This implies that characterization, data acquisition, and modeling of fractured aquifers should be carried out at the scale of the process of interest; unfortunately, this is rarely possible. Often data for fractured aquifers are acquired at several scales over different orders of magnitude, and none of them are at the scale of the process of interest. These scaling issues often make it challenging to develop a workflow of data acquisition, characterization and modeling to achieve useful flow and transport predictions. This talk will illustrate, through presentation of field case histories, factors that have proven to be important in a variety of scales, rock types and geologic settings, and strategies for developing project workflows that focus on these factors. First, the factors that govern the connectivity of the fracture network, and control the spatial variations in this connectivity, at the scale of the process heterogeneity, are often the most important factors to accurately characterize, while other factors play a far less important role. To identify what these factors may be, it is useful to distinguish between three scales: the process scale, the heterogeneity scale, and the data scale(s). The process scale, the scale at which a change in pressure, flow or transport is expected to take place in the aquifer is important for the ultimate project results and a function of time as well; the heterogeneity scale, the scale below which spatial heterogeneity in material properties do not impact the predicted results is critical for mathematical or numerical characterization and not a function of time; and the data scales, which are the scales over which the data reflect fractured aquifer characteristics and are essential for upscaling fracture or aquifer properties to the heterogeneity scale, and may or may not be a function of time. Secondly, it is highly beneficial to collect analogous or complementary data on fracture geometry and network flow response at multiple scales. Third, it is often best to have a lot of “soft” data rather than a little “hard” data. Fourth, given the high uncertainty of any fractured aquifer characterization at virtually any scale of interest, it is exceedingly useful to have a means of validating the aquifer characterization. Methods for validating a model of a fractured aquifer to assess whether it is adequate for the purpose intended will also be discussed.

URL: http://fracman.golder.com

H52B-02 1355h

Fanay-Augères Revisited: Stochastic Continuum Modeling of Flow and Transport in a Crystalline Rock Mass

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A stochastic discrete-fracture model was used by Cacas et al.(1990a-b) to interpret flow measurements and transport experiments in a fractured crystalline rock mass at Fanay-Augères. They considered continuum models to be incapable of properly interpreting small-scale measurements or tracer tests in fractured systems, which in their view require three-dimensional modeling of numerous discrete channels; in their opinion, continuum modeling applies only to average flow on a relatively large scale. Cacas et al. considered their discrete fracture model to have been validated by its demonstrated ability to reproduce selected experimental results. In this paper flow and transport at Fanay-Augères are modeled by viewing the fractured rock as a stochastic continuum in a manner originally proposed by Neuman (1987). The stochastic continuum approach obviates the need for detailed information about fracture geometry or assumptions about how individual fractures control flow and transport. All it requires is the delineation of a few dominant features, which can be embedded into the stochastic continuum model as heterogeneous porous slabs. Though a fault zone has been identified at the Fanay-Augères experimental site, it has been modeled neither by Cacas et al. nor in this paper. In fact, in this paper a larger selection of experimental results than those considered by Cacas et al. are reproduced merely by modeling the rock as a statistically homogeneous continuum in two dimensions. These results demonstrate that a continuum approach may be well suited for the analysis of flow and transport in fractured rock. This does not constitute a validation of the continuum approach, just as the results of Cacas et al. fall short of validating the discrete fracture approach. Instead, the two sets of results illustrate jointly the well-established principle that an open system, especially one as complex as fractured hydrogeologic environments tend to be, cannot be described uniquely on the basis of sparse data and need not be described in great detail to capture its salient behavior by a model.

H52B-03 1410h

Stochastic models of fracture networks based on the broad-range fracture length distribution and the long-range fracture correlations.

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The fact that fractures exist at all scales, and that fracture distributions do not exhibit any obvious length scales except the fracture domain size, poses the question of the relevant model for describing fluid flow in such highly heterogeneous system. Is it possible to use equivalent porous media theory; is it sufficient to consider the major fractures? We tackle these questions by setting up a decision framework for the a priori choice of the modelling framework. Our approach relies on a synthetic fracture-network model based on the geological characteristics of fractures. The first study concerns the connectivity of the fracture network, because connectivity is a prerequisite to any hydraulic property. We then handle the classical hydraulic properties like the equivalent permeability, the flow structure and the well test responses. Non-intuitive results show up. Connectivity is scale-dependent as long as the variance of the fracture length distribution is undefined. It is generally possible to define a homogenization scale mainly function of the fracture density, the fracture length and aperture distributions. This homogenization scale can however be very large splitting the scale range in two parts where fracture networks have different hydraulic behaviours and variabilities. Below the homogenization scale, we have looked for the relevant well-test interpretation framework.

H52B-04 1425h

Field Evidence for Abundant Fracture Connectivity in Sedimentary Rocks

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The behavior of contaminants in fractured rock is strongly dependent on the degree of fracture connection in the fracture network. Although many fracture connectivity studies have been done by cross-hole testing, little is known about fracture connectivity at the scale of contaminant plumes. Field evidence for abundant fracture connectivity obtained from chemical analysis of rock core samples is presented from sites contaminated with chlorinated solvents, such as trichloroethene (TCE), in sedimentary rocks. These analyses determine the contaminant mass in the low-permeability rock matrix. This mass occurs in the matrix due to diffusion-driven mass transfer from the fractures, where all or nearly all the advective transport occurs. The contaminant mass in the rock matrix blocks between fractures represents an imprint of the contaminant migration pattern formed over many years of plume evolution. Vertical core holes were drilled through zones of chlorinated solvent contamination in the depth range of 10 to 300 m bgs at several sites. The chemical analyses were done at close spacing along each core to provide detailed information about concentration versus depth. Also, hydraulic head and other types of borehole information were determined in some of the core holes. The concentration profiles show that the plumes have contaminant mass originating from contaminant transport in numerous fractures rather than just a few fractures with apparent, large, local aperture indicated by borehole hydraulic and geophysical tests. The abundant contaminant migration pathways perceived from the rock core analyses are consistent with simulations of plume behavior using a 2-D model (Fractran) with statistically generated fracture networks of othrogonal fractures with variable apertures and lengths and strong connectivity. Without the constraints on the simulations imposed by the rock core chemical data, the perceptions of the nature of contaminant plumes would be much different.