Report for 2002WA12G: Collaborative Research:Hydraulic and Geomorphic Controls on the Evolution of Cluster Bedforms in Gravel-Bed Streams

Publications

- Conference Proceedings:
  - Hendrick, Ross R., Lisa L. Ely, A. N. Papanicolaou, and Kyle B. Strom, 2004, The role of geomorphic and hydrologic feature on sediment clusters in gravel-bed streams, Washington: A field-based approach, "in" Abstracts with Programs, Geological Society of America Rocky Mountain/Cordilleran Section Meeting, Boise, Idaho, May 3-5, 2005, 36(4):31.
  - Hendrick, Ross R., Ely, Lisa L., Marcell, Janielle L., Papanicolaou, Athanasios N., and Strom, Kyle B., 2005, Tracking the Evolution of Sediment Clusters after High Flow Events, and their Effects on Sediment Transport: Entiat River, Washington: A Field-Based Approach, "in" Abstracts with Programs, Geological Society of America, 37(4):103.
  - Marcell, Janielle L., Ely, Lisa L. and Hendrick, Ross R., 2005, Evolution of Sediment Cluster Morphologies on the American River, Cascade Mountains, Washington, "in" Abstracts with Programs, Geological Society of America, 37(4):45.
  - Strom, Kyle B., Athanasios N. Papanicolaou, B. Billing, Lisa L. Ely, and Ross R. Hendricks, 2005, Characterization of Particle Cluster Bedforms in Mountain Streams, “in” Proceedings of the conference EWRI 2005: Impacts of Global Climate Change (Anchorage, Alaska, May 15-19, 2005), by Raymond Walton, P.E., editor, Reston Virginia.
  - Hendrick, Ross R., Lisa L. Ely, and A. N. Papanicolaou. 2004. The role of geomorphic and hydrologic features on sediment clusters in gravel-bed streams, Washington: A field-based approach, "in" Pacific Northwest Ecosystems Then and Now, Proceedings of the 2004 Meeting of the North Pacific International Chapter of the American Fisheries Society, Stevenson, Washington, November 1-3, 2004, p. 3.
  - Papanicolaou, A. N. and Casey Kramer. 2005. The Role of Relative Submergence On Cluster Microtopography and Bedload Predictions in Mountain Streams, "in" Proceedings of the Fourth International Association of Hydraulic Research

Symposium on River Coastal, and Estuarine Morphodynamics, RCEM 2005, Gary Parker and Marcelo Garcia, editors, Taylor and Francis Group, London, England, p.1083.

- Other Publications:
  - Marcell, Janielle, 2004, Patterns of Sediment transport in the American River, Cascade Mountains, Washington (poster presentation) "in" Thirteenth Regional Conference on Undergraduate Research, Murdock College Science Research Program, Lewis and Clark College, November 19-20, 2004.
  - Kramer, Casey and A. N. Papanicolaou. 2006. The Effects of Relative Submergence on Flow Patterns around Large Particles in a Gravel Bed River, presented at the World Water and Environmental Resources Congress EWRI 2006, May 21-25, Omaha, Nebraska.
  - Strom, Kyle and A. N. Papanicolaou. 2005. Particle clusters in gravel bed rivers. Presented at the International Conference on Civil and Environmental Engineering, Higashi, Hiroshima, Japan, October 2005.
  - Marcell, Janielle and Ross R. Hendrick. 2005. Evolution of sediment cluster morphologies on the American River, Cascade Mountains, Washington. Presented at CWU Symposium on University Research and Creative Expression (SOURCE), May 19, 2005, p. 72.
  - Hendrick, Ross R., Lisa L. Ely, Janielle Marcell, A. N. Papanicolaou, and Kyle Strom. 2005. Tracking the evolution of sediment clusters after high flow events, and their effects on sediment transport, Entiat River Washington: A field based approach. Presented at CWU Symposium on University Research and Creative Expression (SOURCE), May 19, 2005, p. 52.
- Dissertations:
  - Kramer, Casey, 2005, The Role of Relative Submergence on Cluster Microtopography and Bedload Predictions in Mountain Streams, M.S. Thesis, Civil and Environmental Engineering, The University of Iowa, Ames, Iowa, 99 pages.
  - Hendrick, Ross H., 2005, The Role of Geomorphic Features and Hydrologic Processes on Sediment Clusters in Gravel-Bed Rivers, Washington: A Field-Based Approach: M.S. Thesis, Geological Sciences, Central Washington University, Ellensburg, Washington.

Report Follows

PROBLEM AND RESEARCH OBJECTIVES

1. Develop a stage-discharge relation to determine the required flow conditions for cluster development and disintegration in the field at the American and Entiat River sites.
2. Analyze the flux of individual sediment particles through cluster bedforms.
3. Evaluate the role of relative submergence on the formation and evolution of cluster microforms in gravel bed streams and its implications to bedload transport.

METHODOLOGY

Stage data for the American River site was collected and logged for high flows in 2003 and 2004 with the Global Water Instruments water-level recorder, which was installed at the site in Spring, 2003. The discharge at the Entiat River was determined directly from the USGS gage. Channel cross sections were surveyed on both rivers, and velocities at the American and Entiat River sites were calculated using the HEC-RAS water-surface profile model.

Clusters were marked, photographed and surveyed before and after each major high-flow event. Sediment movement within individual clusters was analyzed from photographs.

In the laboratory, an enhancement of the methodology was attempted in order to account for the role of relative submergence on cluster microtopography, a very important feature in gravel-bed rivers that few to none have researched in a systematic way. More specifically, the methodology and experimental design of this research was based on the premise that in natural gravel bed streams, where the height of clast-obstacles is generally of the same order of magnitude with the flow depth, the processes between the interaction of the flow and clasts plays a dominant role in eddy taxonomy and flow prevailing mechanisms.

PRINCIPAL FINDINGS AND SIGNIFICANCE

Entiat River Study Site. On the Entiat River, the evolution of cluster beforms and movement of individual sediment particles within clusters were monitored for 4 peak flows that inundated the study site. The peak flows were Oct., 2003, 57 m^3s^{-1}; Nov. 2003, 13 m^3s^{-1}; May 2004, 39 m^3s^{-1}, and Jan. 2005, 22 m^3s^{-1}. Sediment cluster bedforms had a measurable impact on sediment entrainment during the two intermediate flow events of 22 and 39 m^3s^{-1} that inundated the gravel bar at the study site. Under these flows, the critical shear stress required to entrain sediment particles was 38-51% greater for sediment within clusters than for isolated sediment particles on the gravel bar. All clusters were mobilized during the highest peak in the 2-year record, 57 m^3s^{-1}, which occurred in October, 2003. Therefore the clusters did not significantly impact the overall sediment transport during this event, as the entire bed was mobilized at the study site. No measurable sediment movement occurred within the clusters during the lowest inundation event of 13 m^3s^{-1}. The mean annual peak flow on the Entiat River is ~80 m^3s^{-1}, which means that on average, sediment clusters on this river are are likely at least partially mobilized and reformed on a semi-annual basis. At site 1 on the Entiat River, which had a fairly well-sorted sediment size distribution, the diamond cluster form was the most stable over the 2-year period. At site 2, with a greater range of sediment sizes and larger anchor clasts, all cluster forms were equally stable.

American River Study Site. Six types of clusters were observed at the study site on the American River. The six types include upstream triangle, downstream triangle, diamond, ring, line and transverse line. Our focus was the evolution of the cluster morphologies during periods of moderate

peak flows. It was our hypothesis that this evolution would only occur during moderate flow conditions because during high flow periods the clusters would be completely reorganized. On the American River the 2003 peak flow was 31.5 m3/sec and the 2004 peak flow was 24 m3/sec, which are moderate-sized annual peaks compared to the historic record. Our hypotheses were that 1) transverse line clusters are incipient forms that would ultimately transform into upstream or downstream triangles; 2) upstream and downstream triangle clusters are intermediate cluster forms which ultimately form diamond clusters; and 3) diamond clusters are the final cluster form and are therefore the most stable. The results were that no flows during the 2-year period were sufficient to mobilize the sediment clusters, and all cluster forms were therefore stable throughout the study period. In contrast, individual sediment particles were added, moved and removed from the clusters. The diamond clusters experienced the greatest amount of individual sediment movement through the stable cluster bedforms and the transverse lines the least.

Additional analyses include: 1) examination of critical shear stresses involved in sediment entrainment, 2) determination of cluster density at different sites, 3) incorporation of sediment and flow data into the 3STID flow model at the University of Iowa to refine the bed-velocity calculations at the cluster sites and 4) analysis of the geomorphic settings of gravel clusters.

The field study areas on both rivers have experienced below-average peak flows during the 2-year study period. This period of low to moderate flows was advantageous because we were able to investigate the flux of sediment through the stable cluster forms without the complete destruction and reorganization of the clusters. Understanding the sediment movement through the clusters helps determine the sediment flux and transport patterns throughout the stream. The response of the channel bed morphology to flows in unregulated rivers such as the Entiat and American Rivers, has practical implications for river management, channel restoration and maintenance of aquatic habitat in regulated streams by guiding the determination of peak discharges necessary to maintain or mobilize cluster bedforms.

Laboratory component. The laboratory nature of this investigation allowed for the first time the isolation of the relative submergence on cluster formation. This was accomplished through a carefully planned experimental design and facilitated detailed sediment, geomorphological, and flow observations/measurements under well controlled conditions. These observations/ measurements were made for different flow and sediment feeding rates and for different fractions of sediment sizes. The observations and measurements extended to conditions corresponding to the rising limb of a hydrograph. State of the art equipment and laboratory techniques were utilized in order to meet the research needs of this work. Overall, 16 experimental runs were conducted to obtain unique quantitative sediment observations with the addition of 3 experimental runs performed, to quantitatively describe the flow patterns around the clasts.

The results of this study focused on the qualitative evaluation of the bed microtopography for the high and low relative submergence, a quantitative description of the bedload transport rates and their statistical properties, a detailed analysis of the flow characteristics around a clast, and the coupling of flow with bed microtopography observations around a clast for a selected number of experimental runs.

For the low relative submergence, the presence of the fixed clasts indirectly affected the depositional patterns of the incoming sediment by creating troughs within the clast section, which are the areas where the deposition of the incoming sediments predominately occurred.

For the high and low relative submergence experiments clasts/clusters worked as a sink for the incoming sediment, thus affecting the magnitude of the exiting bedload rate and causing perturbations to sediment motion. The cycle of cluster formation and breakup by the flow was observed for all runs. A similar observation regarding cluster breakup has been documented by Strom et al. (2005). Strom et al. (2005) found that clusters worked as a sink and source of sediment.

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Strom, Kyle B., Athanasios N. Papanicolaou, B. Billing, Lisa L. Ely, and Ross R. Hendricks, 2005, Characterization of Particle Cluster Bedforms in Mountain Streams, "in" Proceedings of the conference EWRI 2005: Impacts of Global Climate Change (Anchorage, Alaska, May 15-19, 2005), by Raymond Walton, P.E., editor, Reston Virginia.