fractions that compose a mixed size sediment is controlled by the pocket geometry within which grains rest and the size of grains that compose the surface layer. They hypothesize that as pockets fill with finer sediment, there is a reduction in the momentum loss caused by wake formation on particles projecting into the flow, and those projecting particles experience increased drag as the near bed flow velocity increases. Whiting et al. [1988] suggest that this process results in a grain grain interaction whereby coarse particles are plucked from the bed by increased drag and coarse particles remain in motion because distrainment sites are filled with fine sediment. Whiting et al. [1988] proposed that the patchy nature of this infilling and the tendency for large grains to concentrate during the transport process could be responsible for bed load sheet formation. This roughness perturbation in the bed surface grain size has been linked to the growth of bed load sheets [Seminara et al., 1996]. Dietrich et al. [1989] noted that when sediment supply to a channel is reduced, the availability of fine particles to infill pockets is reduced and the zone of active transport is restricted.

[4] Kirchner et al. [1990] and Buffington et al. [1992] further expanded on this work by examining the effects of the sediment size distributions on the friction angle that controls sediment entrainment. They demonstrated that as particles increase in size relative to the bed material surface, particle protrusion increases, which exposes greater proportions of large particles to the flow and projects the particle farther above the mean bed elevation. Kirchner et al. [1990] used a simple analytical model to demonstrate that increased particle projection increases the lift and drag forces on particles, increasing the likelihood of entrainment.

[5] In spite of our growing understanding of how sand additions to gravel beds affect sediment transport rates, direct measurements documenting the key linkages between near bed velocity, pocket infilling with fine material, and large grain mobilization have not been obtained. Also, it remains unknown whether gravel beds can be mobilized by additions of finer gravel by the same mechanisms as proposed for sand, although a number of authors have suggested this may be the case [cf. Wilcock and Kenworthy, 2002]. There is considerable interest in the problem from applied river scientists who seek to mobilize static river beds downstream from dams in an attempt to rejuvenate salmon spawning gravels. Gravel augmentation of finer gravel (without adding sand) may be able to unlock these beds.

[6] Here we conduct flume experiments to test the hypothesis that static coarse surface layers in gravel bedded rivers can be mobilized through addition of suitably finer gravel bed load to the channel. We find that mobilization occurs and that local measures of velocity and turbulence support the mechanisms proposed by Ikeda [1984] and Whiting et al. [1988]. Our results imply that it is the grain 427720.7301im241lay2rl measures[e.g.,6

single small and large pulses as well as multiple pulses where four pulses were added to the channel with a short intervening period (labeled a, b, c, and d in order of occurrence; Table 1). Out of the seven pulse experiments completed, we focus here on runs 10 and 21, which were the large the pulse on the bed. The difference profile after 7 h suggests that while the specific locations of topographic highs and lows have changed from the beginning of the experiment, the mean elevation was the same as the prepulse

the sensor array because ‾ increased as the crests of low amplitude waves passed and decreased as troughs passed.

[24] Overall, ‾$_2$ mirrors ‾ (Figure 4b). During pulse passage, ‾$_2$ exceeds ‾, probably because the low amplitude waves of the pulse offered some form of resistance to flow not considered in the ‾$_2$ calculation. However,

the coarsest particles in the bed material, which were static prior to the pulse, is increased. Because distrainment pockets have been filled by fine particles, the coarsest particles remain in motion.

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tial to release fine material trapped beneath the surface and temporarily fining the bed. Sand cannot be used to mobilize static gravel beds because of a perceived damaging effect on salmon spawning and rearing habitat. Our results suggest that coarse immobile gravel downstream of dams can be mobilized by adding sediment pulses composed of the fine gravel tail of the channel bed surface grain size distribution.

5.

[38] Adding sand to gravel beds is known to greatly increase gravel mobility and flux. Here we demonstrate that additions of fine gravel to a coarser gravel bed can also increase the flux of the coarser gravel bed material. Our experiments demonstrate that finer gravel will fill the interstitial pockets in a coarse surface layer, mobilizing an otherwise static bed. Fine gravel pulses cause systematic changes in channel hydraulics that promote the mobilization process. As fine pulses pass over a gravel bed, the water surface drops, mean flow and near bed velocities accelerate, and turbulent kinetic energy declines, indicating a decline in the turbulent fluctuations at the bed. However, the increase in coarse particle movement suggests that the increase in drag caused by the accelerated flow may be sufficient to overcome the decline in turbulent fluctuations. Our findings suggest that expressions for the influence of sand on gravel beds need to be generalized as a critical ratio of the finer sediment to the coarser bed material.

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