Geomorphic Response to Gravel Injection, Channel Restoration and Peak Flows in Clear Creek, CA

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Abstract

The impoundment-induced coarse sediment deficit and concomitant reduction in habitat quality in Clear Creek below Whiskeytown Dam has been well documented by various investigators (Coots 1971, McBain and Trush 2001). Clear Creek is located in northern California, in the transition between the Klamath Mountains (a bedrock gorge) and the Central Valley (an unconfined, alluvial reach). Historic gravel mining and gold dredging resulted in large scale channel and floodplain disturbance in the alluvial reach. Whiskeytown Dam, closed in 1964, impacted all downstream reaches with flow regulation. Effects of the impaired flow regime and reduced coarse sediment supply include: an overly simplified channel, riffle coarsening, fossilization of alluvial features, reduced rates of channel migration, reduction of fine sediment supply for overbank deposition, and reduction in the amount and quality of spawning gravels for available for anadromous salmonids. Infrequent dam spills winnow, but lacking sediment input, do not replace mobile bed sediments. In some reaches, reduced coarse sediment supply, compounded by gravel or gold mining, resulted in incision to bedrock and a loss of channel dynamism and floodplain connectivity.

Restoration efforts to address habitat degradation include temperature-control flow releases, gravel injection, channel realignment and floodplain grading and extensive riparian planting. The focus for many projects is on geomorphic-process restoration (e.g. bed scour and redeposition related to gravel injection). Restoration of a “natural” channel and floodplain, in combination with gravel injection and appropriate flow releases, is intended to initiate and sustain sediment transport processes thereby enhancing ecological function. A “natural” channel in this case is defined as one whose physical structure and interaction with the contemporary flow/sediment regime approximates the pre-dam condition, albeit at a smaller scale. Gravel injection is intended to replace the pre-dam sediment supply and hydrograph manipulation (coupled with naturally occurring uncontrolled spills and below-dam tributary floods) was intended to replace impaired hydrograph components (e.g. winter peaks and spring runoff). Efforts to manipulate the hydrograph have been limited to spring pulse flows (on the order of 800 cfs), much lower than the intended gravel-mobilizing flows of at least 3,000 cfs (McBain and Trush 2001, Stillwater 2013). Gravel injection sites have been developed at 15 locations. Most injection sites provide passive gravel recruitment during high flows, e.g. lateral berms and talus cones. Over 200,000 tons of gravel have been added over 20 years resulting in dramatic (orders of magnitude) increases in below-dam spawning habitat.

Controlled pulse flows are limited to a maximum of 1,200 cfs by the dam’s outlet works, though 800 cfs is more typical due to operational constraints. Spring pulse flows, implemented since 2009, were developed for biological considerations related to anadromous salmonids. For context, the post-dam 1.5-year event is 2,240 cfs. Since the large floodplain restoration projects were designed to flow overbank at 3,000 cfs (the 2.0-year event) and since the channels were designed to become active at this threshold (e.g. channel will migrate and form new alluvial features), the 800 cfs pulse flows were assumed to provide minimal geomorphic benefit (e.g. scour and re-deposition of coarse sediment). During drought years however, it became apparent that these relatively minor flows (much smaller than the average annual post-dam peak flow) were

capable of fulfilling a vital function in the restoration of Clear Creek: the mobilization and redistribution of injected gravel. Spring pulse flows mobilized lateral berms and talus cones but had little effect on most placed riffles. This capacity to perform geomorphic work is especially pronounced in the near-dam reaches, where floodplain and channel restoration have not occurred, only gravel injection. This paper will explore the role of gravel injection in two very different geomorphic settings: the confined, near-dam reach and the unconfined, alluvial central valley reach where extensive channel and floodplain restoration has been implemented.

The near-dam reach (the first two miles below Whiskeytown Dam) is fairly confined (relic floodplains are about as wide as the active channel) is bedrock controlled (riffle crests are keyed to bedrock) and is steered by topography (channel alignment parallels valley walls). Pre-gravel injection, the reach exhibited quasi-alluvial characteristics in the form of skeletal point bars, coarse riffles and persistent gravel lobes associated with favorable hydraulic settings (e.g. high flow eddies below islands). Due to its proximity to the dam, the ambient coarse sediment load into the reach is essentially zero (tributary contribution is minimal). Gravel injection occurs via a large talus cone immediately below the dam and at several riffles along the two-mile reach where gravel is placed directly in the channel. Riffle supplementation provides immediate benefit in the absence of high flows (fish utilize the placed gravels). Both strategies contribute to the longer-term goal of providing coarse sediment for fluvial redistribution.

The large channel/floodplain restoration projects occur downstream in unconfined, low gradient reaches and (in their restored state) are largely governed by purely alluvial processes. A sinuous channel has been realigned away from shallow clay pan through areas of deeper (though highly disturbed) valley sediments and is free to migrate within a broad floodplain. Ambient coarse sediment load into the restoration reach has been enhanced by removal of a relict dam (liberating >60,000 cubic yards of stored mixed sediments) and by ongoing upstream gravel augmentation. The hydrologic setting for the downstream reaches is notably different, due to tributary accretion. Floods (as high as 12,000 cfs) occur even when flows in the upper reach remain near base-level (200 cfs). A very steep, confined bedrock gorge separates the two reaches.

Gravel injection in the floodplain reach was accomplished via a massive (75,000 tons) "transfusion" during construction of the downsized (3,000 cfs capacity) channel. Large segments (pool tails and riffles) were blanketed with spawning sized gravels (1 to 5 inch), which set the stage for fluvial redistribution. Immediately following construction of the first phase (2002), fall run Chinook Salmon (*Oncorhynchus tshawytscha*) began to spawn in the placed gravels. Five flow events in Water Year (WY) 2003 exceeded the channel capacity (and designed bed mobility) threshold of 3,000 cfs and a prolonged dam spill exceeded 3,000 cfs for over 36 hours in April. The channel evolved into a slightly longer, more sinuous alignment, creating new alluvial features (medial and point bars) as it migrated. Tracer gravel studies showed the riffle crests to be 100 percent mobile at flows exceeding the design threshold (Graham Matthews & Associates, 2004). All of these dynamic responses were aligned with the geomorphic performance objectives for the new channel. Nonetheless, the restoration team remained concerned that without additional sediment supply, the highly active channel might return to its previously degraded state so an adaptive gravel injection program was developed.

An average of 5,000 tons per year was injected via a talus cone in a bedrock gorge 1.6 miles upstream of the floodplain restoration project. The ambient supply coming into the reach increased as liberated dam sediments and injected gravels arrived: upstream pools partially filled and bars increased in height and area (Graham Matthews and Associates 2016). Other injection sites (lateral berms and riffle supplements) were developed within the project footprint to enhance key sites where incision to claypan (an undesirable response) began to occur in areas of higher shear stress (steeper riffles and along the outside of bends). During low water years, the spring flow dam releases (~800 cfs) mobilized nearly all of the lateral berms within the project (some gravels remained perched on higher surfaces). As evidenced by topographic differencing, riffles immediately below injection sites (on the order of hundreds of feet) aggraded and claypan exposures were at least partially buried. During higher flow water years, the signature of injected gravel was not clearly detectable as gravels were absorbed into the overall channel response to high flow events, but the channel continued to respond in a favorable manner: highly dynamic bars changes, limited claypan exposure, continued planform evolution. Based on annual geomorphic monitoring results, managers assumed that the annual injections (approximately 1,700 tons per year) were making a positive contribution. Annual injections continue through this writing.

Gravel injection in the floodplain reach is clearly beneficial, but in the upstream reach, where no large-scale restoration was performed, the role of gravel injection is most compelling. In this reach, the large talus cone at the dam and three riffle-supplement injection sites have "recharged" (gravel-coated a significant portion of the bed) nearly the entire two-mile reach. This recharge was for the most part achieved under a highly regulated flow regime, as compared to the lower reaches. Since 2003 only two very brief peak flow events (1,000 to 2,000 cfs) have exceeded the typical spring flow release magnitude of 800 cfs. The importance of these relatively small events cannot be overstated from a geomorphic recovery perspective. Without them, only a small percentage of the two-mile reach would likely have been recharged. Gravel injection response relative to flow events has been carefully tracked with spawning gravel area mapping, topographic surveys, aerial photo analysis, bar mapping and visual channel condition (composition and function) assessments.

In addition to creating spawning habitat, gravel injections have induced positive geomorphic changes which represent a shift in the trajectory of Clear Creek's geomorphic response to impoundment. Alluvial form and function have been enhanced as highly dynamic and complex bar sequences develop along gravel "waves" as injected gravels propagate downstream. Scour and deposition associated with these waves disrupts riparian colonization which had evolved into a robust state under the post-dam flow regime. Sand delivery from the few below-dam tributaries, while modest in terms of annual contribution, interacted with the bank vegetation to create berms. These riparian berms not only "lock up" gravels available for transport, they contribute to channel confinement, increasing water velocities and impacting juvenile salmonid habitat quality. Gravel waves cause mechanical disruption to riparian areas as well as divert flow (as a function of bar height) toward banks causing undercutting, lateral scour and channel migration.

Complex flow patterns develop across depositional bedforms which benefit aquatic organisms by promoting heterogeneous hydraulic conditions: increasing hyporheic flow and changing flow depth, velocity and direction. Armored features become more mobile as finer particles infiltrate and "lubricate" bars and riffles. Increased floodplain connectivity occurs as the result of gravel waves decreasing channel capacity and forcing stream flow up out of the channel onto adjacent surfaces. Raising the near-channel water table also appears to increase alder mortality, further reducing riparian confinement and increasing woody debris loading which in turn increases the degree of mechanical disruption; high flows with a high woody debris component are more effective at disrupting established riparian vegetation.

The primary geomorphic recovery goals on all of the below-dam reaches of Clear Creek require high flows and sediment contributions as the agents of change (McBain and Trush 2001). Efforts to establish a high flow release program (Stillwater 2016) similar to the program implemented on the Trinity River (U.S. Department of the Interior and U.S. Bureau of Reclamation, 2000), have to date proven unsuccessful. Despite the lack of a high flow management program, carefully planned gravel injection, coupled with relatively small pulse flows has proven highly successful in aiding the recovery of floodplain/channel restoration projects and offsetting the progressive near-dam channel degradation by restoring a suite of beneficial sediment-related geomorphic processes.

References

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