Maintaining and Restoring Sediment Load Downstream of Dams

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Dams interrupt the natural continuity of sediment movement through river systems, creating problems not only within the reservoir (lost capacity and function due to sedimentation), but also, downstream, where sediment-starved flows can erode the channel bed and banks, accelerate erosion of coasts and deltas, and result in loss of instream habitats. Whether the reach below a dam is sediment starved or in sediment surplus depends on the balance of the sediment supply and post-dam sediment transport capacity. Below large dams that significantly reduce high flows, the river may not have sufficient energy to move tributary-supplied sediment (or its coarsest fractions), resulting in buildup of tributary deltas and/or general channel aggradation. However, more commonly, the transport capacity is greater than the sediment available, and the resulting 'hungry water' causes incision and bed coarsening in the channels downstream (at least until the sediment deficit is compensated by tributary input and/or sediment derived from erosion of bed and banks).

Sediment routing around or through dams (by sediment bypass channels or sluicing through outlets in the dam) can mitigate this effect by restoring at least part of the natural sediment load. Where feasible, these approaches are sustainable in that they use the river's energy to supply the natural sediment load to the downstream reach, and they contribute to reservoir sustainability by reducing the rate of sediment accumulation. More commonly, coarse sediments are mechanically placed in the river downstream of dams to partially mitigate the sediment starvation, requiring ongoing maintenance, and usually not reducing reservoir sedimentation. The vast majority of these gravel augmentation projects have been implemented to restore habitat, especially spawning habitat for anadromous salmonids, but the largest single gravel augmentation project is to prevent bed incision downstream, to prevent undermining of infrastructure: on the Rhine River below the Barrage Iffezheim.

In northern California, gravels have been added below dams on over 20 rivers, totaling over 400,000 m^3. These projects have all been undertaken to improve habitat for salmon and trout in downstream channels, and with one exception, the gravels used have come not from sediment deltas in the reservoirs themselves, but other sources, including tailings left from historical gold dredging. The early projects were mostly construction of spawning riffles, often by placing lines of boulders across the channel and back-filling with gravel suitably sized for spawning by salmon or trout. As these projects failed or required maintenance over time, an alternative approach has become more common: to inject gravel for redistribution by flows and ultimately deposition in riffles for spawning. The largest amounts of gravel have been added to the Sacramento River mainstem, its tributary Clear Creek, and the Trinity River, most of whose flow is diverted to the Sacramento. Both Clear Creek and the Trinity have undergone extensive augmentation of gravels downstream of dams, modifications to the flow regime, and restoration projects to improve bank and floodplain connectivity. The Trinity River has arguably the most comprehensive program of sediment augmentations, deliberate high flows released to restore natural processes of sediment transport and deposition, and to a lesser extent, physical manipulations, which have resulted in increased channel complexity and habitat for anadromous salmonids. Detailed study of gravel bars on the Trinity indicates that the bars consisting of fresh gravel deposits (derived from gravel injections upstream) had greater hyporheic flow, and consequently better modulated water temperature and retained suspended particulate organic matter than mechanically-constructed bars.

The Mekong River basin, Southeast Asia, is undergoing extensive dam construction, with 140 major dams built, under construction, or planned for the mainsteam river and its tributaries. These dams are virtually all to produce electricity, which will mostly be exported to neighboring markets in Thailand, Vietnam, and China. If these dams are all built as currently planned, application of the 3W model indicates that they will trap 96% of the natural sediment supply to the Mekong Delta. The Delta is a highly vulnerable landscape, already experiencing subsidence, both natural and accelerated from groundwater pumping, and accelerated coastal erosion. Sediment supply to the Delta has already been reduced by extensive sand and gravel mining, mostly in Vietnam and Cambodia (some used locally in construction and to fill wetlands, some exported to markets such as Singapore). Thus, cutting off the supply of sediment from upstream can be seen as an existential threat to the Delta. However, if planned dams can be rethought and redesigned, in many cases it may be possible to implement sustainable sediment management approaches, such as sediment bypasses or passing sediment through dams. Thus, it may be possible to reduce the sediment trapping and thereby allow more of the natural sediment load to reach the Delta. A related impact of dams is blocking the migration of fish to their spawning areas in tributaries upstream. By relocating and redesigning dams, in some cases barriers to fish migration can be avoided, as currently being explored by Cambodian and Laotian government staff working with international experts.

Looking at the reservoir itself, accumulation of sediments creates a host of problems, from suspended sediments abrading turbine blades, to interfering with intake structures, to outright filling of reservoirs with sediment, displacing water storage volume. Sediment problems are typically evident long before the reservoir completely fills with sediment, but completely filled reservoirs are the most obvious manifestation of this problem. Many dams suffer from structural stability problems to begin with, and accumulating a wedge of sediment against their upstream side only exacerbates the problems. As illustrated by Barlin Dam on the Dahan River, Taiwan, such sediment-filled dams can release enormous pulses of water and sediment in a matter of hours. In California, an analysis of sediment yields by geomorphic region, coupled with application of the 3W model, predicted where in the state reservoirs would be likely to fill. Small water supply reservoirs are more vulnerable to filling with sediment by virtue of their small initial capacity, and those located in the Coast Ranges are most vulnerable by virtue of high sediment yields there.

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