

Channel Margin and Eddy Bar Deposition Along the Colorado River in Grand Canyon NP

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The characteristics of biologically important, riverine environments depend directly on the nature of flow and sediment transport in the river channel, and on the mechanisms and rates of exchange of sediment between the deposits near the banks and the channel. Owing to the sensitivity of the riparian habitat to riverine processes, alteration of the river discharge or the sediment input can have a substantial impact on this important ecological zone. Consequently, the choice of dam release regimes should be guided by a scientifically founded, environmentally sensitive management plan. Such a plan should be based on a precise knowledge of the dominant flow and sediment transport processes in the river and on a comprehensive understanding of the interplay of these physical processes with the salient biological and chemical features of the riparian zone.

Since 1983, the Glen Canyon Environmental Studies Office of the U.S. Bureau of Reclamation has supported a comprehensive set of investigations to determine the effects of operational flow releases from Glen Canyon Dam on the riparian and aquatic resources of the Colorado River. Many individuals representing several federal and state agencies have contributed to this effort. Research concerning the downstream changes in flow characteristics under various discharge regimes, the associated transport of sediment, and changes in important channel deposits has been the object of a cooperative effort by the NPS and the USGS. The goal of this research is to develop a comprehensive model that can be used to study the response of the riparian ecosystem of Grand Canyon NV to alternative flow regimes.

Canyon Geomorphology

The Grand Canyon began to form about 8-10 million years ago as the Colorado River cut deeply into the rising Colorado Plateau. As a consequence of the deep channel incision, debris from rock falls (talus) and bedrock, rather than fluvial sediment, are the most common bank materials. Furthermore, tributary channels are short and steep. Occasional debris flows and large floods in these tributaries add coarse material

to the main channel in the form of deposits that partially block the channel. These constrictions cause backwater pools on the upstream sides, rapids over the top, and the cutting of deep pools into bedrock downstream of the debris deposits. Both the upstream and the downstream pools are depositional sites at moderate river flow, but the downstream pools become active zones of scour under prolonged periods of extreme discharge. Since closure of the Glen Canyon Dam in 1963, the peak flows have been too small to move the coarsest material.

The large load of suspended sand and irregular width and depth of the Colorado River results in a channel with numerous local areas of erosion and deposition. Connected bands of sand along the channel edge are called "channel margin deposits". In the Grand Canyon, these now provide the substrate for narrow zones of dense vegetation, which, in turn, form habitat for a wide variety of terrestrial organisms. Larger accumulations of sediment are deposited at the downstream ends of rapids where abrupt increases in channel width cause flow separation and hence, stream edge recirculation zones

(called eddies). In these eddies the near-bank current is in the up-river direction, and the prolonged retention of sediment laden water entering them from the main channel results in rapid deposition of the suspended sand and silt. "Eddy bars" created beneath recirculation zones during periods of high flow and exposed when the river stage falls can be quite large and are a more suitable substrate for riparian vegetation than debris fans, (see Fig. 1).

Flow and Sediment Transport

Daily, monthly and annual flows of the regulated Colorado River are very different from those of its free flowing predecessor. These changes in flow patterns have had a significant effect on the downstream environment. Prior to the construction of Glen Canyon Dam, the Colorado River through the Grand Canyon had an average annual discharge peak of more than 90,000 cubic feet per second (cfs) and, except during major flash floods in tributaries, discharge and river stage changed slowly from day-to-day. Operation of Glen Canyon Dam has reduced the maximum annual peak discharge to less than 33,000 cfs in most years, but has

greatly increased the daily range of discharge. Depending on electrical power demand, daily fluctuations of the river stage can reach 14 feet. This change from seasonal to daily variation has had a significant effect on the riparian environment. In addition, the main supply of sediment to this reach of the Colorado River is now deposited behind Glen Canyon Dam. The annual pre-dam sediment flux past the mouth of Bright Angel Creek (near Phantom Ranch) was 95 million tons of sand, silt and clay. Today only about 11 million tons per year of sediment, on average, are supplied annually by tributaries to the Colorado River downstream from Glen Canyon Dam. Although these changes in river discharge and sediment input are large, Glen Canyon Dam still can be operated to maintain critical river resources, including



Figure 1. An eddy bar deposit downstream from Nankoweap Canyon. Such deposits are commonly the only suitable camping sites for river trips. This bar was deposited by large discharges during 1983-85, and now (1992) thickly vegetated.

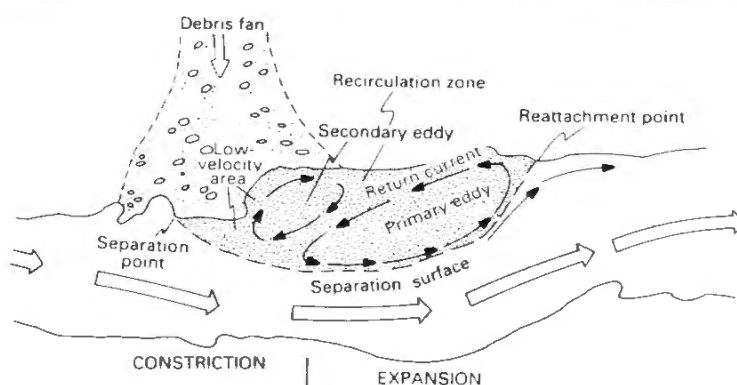


Figure 2. Flow pattern in a typical recirculation zone, (figure from Schmidt and Graf, 1990)

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channel margin and eddy bar deposits.

Deposition and Erosion of Eddy Bars

When a river channel widens abruptly, the inertia of the rapidly moving fluid near the center of the channel causes this high velocity core to continue more or less straight downstream, departing or "separating" from the abruptly diverging bank. Flattening of the downstream component of the river surface slope, however, also causes the high velocity core to decelerate and spread laterally. Eventually the core of rapidly moving fluid reaches the bank or "reattaches". Adjacent to that bank between the points of separation and reattachment the fluid moves in the upriver direction (recirculates) Figure 2. Typically the high velocity core decelerates at an increasing rate, causing the boundary between the slowly moving fluid in the outer part of the recirculation zone and the more quickly moving fluid at the outer edge of the high velocity core to curve towards the bank. This curvature causes a net outward flow near the river surface and a net inward flow near the bottom, producing an extremely effective trap for suspended sand which travels in higher concentration near the river bed. Once this sand is carried into the recirculation zone where the turbulence levels are substantially lower than in the main channel, it settles to the bottom and moves as bed load, that is, by rolling and hopping along the bottom.

Only during periods of exceptionally high flow is sand carried through the recirculation zone in suspension, and even then most of the material is retained in and deposited beneath the eddy. This process operates on all scales, but small embayments fill rapidly with sediment and the deposits often are washed out again as the stage rises. Such small-scale deposits usually are preserved only when produced by very high-stage events, and preservation is aided substantially when relatively dense stands of vegetation become established between infrequent large floods. The outer edges of these channel margin deposits are eroded by subse-

quent flows of lower stage, causing cut banks that give the impression of extremely rapid erosion. These channel boundaries, however, are very dynamic and rapid erosion at one range of discharge is often followed by rapid deposition. Conversely, slow erosion often is a consequence of negligible deposition.

Channel margin deposits and eddy bars are eroded by several mechanisms. The most effective of which occurs when flow overtops an upstream obstacle resulting in elimination of the recirculation zone and a return to downstream flow near the bank. This situation usually produces a large local increase in the sediment transport rate and, hence, erosion of the previously deposited material. Sand deposits also can fail and slump into the channel when erosion removes the supporting toe of the sand bar. This mechanism is enhanced by an elevated water table that creates excess pore pressure in the deposit, when river stage falls quickly. Wind erosion of exposed eddy bars also is an effective process degrading these deposits.

The continued presence of high stage channel margin and eddy bar deposits in the Colorado River through Grand Canyon NP depends on their occasional reconstruction during high discharge events. These deposits, in fact, consist of sediment grains for which the downstream movement has been interrupted temporarily. Although a particular sand bar may appear to persist for years or decades, there is a continued exchange of sediment between the deposit and the river. Eddy bar deposits exist where there is sufficient deposition in the long term to replace local erosion. A proper accounting of the complex interplay of processes responsible for bar deposition and maintenance, each occurring at a rate that depends on the flow and available supply of sediment, requires a combination of precise field observations and carefully constructed, fluid dynamic models.

Conclusion

There is a very close relation between the discharge history of a deeply incised river in an

arid region, and the riparian environment of that river. Owing to the incision and the need for water in surrounding areas, such rivers are prime candidates for impoundment. Unfortunately, the environmental effects of flow regulation on such rivers can be considerable and until recently these effects have not been carefully assessed when planning dam operations. The Glen Canyon Dam, which discharges into the Marble and Grand Canyons, is an obvious example of a structure that could be managed more efficiently using recently procured scientific knowledge. Extensive research currently being carried out concerning flow, sediment transport, eddy beach deposition and maintenance of riparian habitat in this segment of the Colorado River is producing a sound foundation for environmentally sensitive management of this dam. It is likely that this research will lead to knowledge and operational models that also can be used effectively for river management in other national parks and recreation areas.

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Selected References

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