Geomorphic Trajectories in the Lower Yuba River, California after 150 Years of Severe Human Disturbance

Trajectoires Géomorphologiques dans le Cours Inférieur de la Rivière Yuba, Californie, après 150 ans de Perturbation Humaine Sévère

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RÉSUMÉ

Pour les grandes rivières qui ont été très altérées par l’activité humaine, la trajectoire du changement doit être comprise afin qu’une réhabilitation durable soit viable. Cela implique une période de temps plus longue que celle généralement adoptée dans le cadre de la gestion des fleuves aux États-Unis. Reconstitutions géomorphologiques et preuves historiques sont souvent rejetées en faveur de solutions d'ingénierie qui soulignent la stabilité de chenal sans une compréhension complète des tendances sous-jacentes à de grandes échelles d'espace et de temps. Cet article présente l'histoire géomorphologique d’un corridor de 40 km dans la plaine d’inondation sur le cône alluvial où le cours inférieur de la rivière Yuba (Lower Yuba River, LYR) quitte la Sierra Nevada et pénètre dans la vallée de Sacramento en Californie du Nord. G.K. Gilbert a rendu célèbre ce système fluvial en documentant la sédimentation volumineuse causée par les mines hydrauliques dans les montagnes. Par la suite, le dragage et la canalisation ont perturbé encore davantage le LYR, qui est maintenant une rivière très ingénierie, et des concentrations élevées de mercure élémentaire ont été trouvées dans le sédiment minier. La morphogenèse des plaines inondables et l'ingénierie de la LYR fournissent un exemple extrême d'un système perturbé pour lequel la reconnaissance de l'histoire du changement est essentielle à la gestion durable de la rivière.

ABSTRACT

When large rivers have been extremely altered by human activities, the trajectory of change needs to be understood in order for sustainable river rehabilitation to be viable. This involves a longer time frame than is typically adopted for river management in the United States. Geomorphic reconstructions and historical evidence are often dismissed in favor of engineering solutions that emphasize channel stability without a full understanding of underlying trends at large scales of space and time. This paper presents the geomorphic history of a 40-km corridor of floodplain on the alluvial fan where the Lower Yuba River (LYR) leaves the Sierra Nevada and enters the Sacramento Valley in northern California. This river system is famous from G.K. Gilbert’s documentation of voluminous sedimentation caused by hydraulic gold mining in the mountains. Subsequently, dredging and channelization further disturbed the LYR, which is now a highly engineered river, and high concentrations of elemental mercury have been found in the mining sediment. Floodplain morphogenesis and engineering of the LYR provides an extreme example of a disturbed system for which recognition of the history of change is essential to sustainable river management.

KEYWORDS

Fluvial geomorphology, floodplain morphogenesis, mining sediment, river management

1 INTRODUCTION

Settling of the New World initially involved the rapid introduction of new technologies without environmental constraints on their application. Rampant deforestation and mining rapidly ensued that resulted in environmental destruction in a land that had not previously known a machine or industrial age. An extreme example of geomorphic damage to a fluvial system is the devastation to rivers in northern California along the eastern Sacramento Valley following the gold rush in the late 19th century. Sediment produced by hydraulic gold mining caused deep floodplain aggradation and elevated river flood stages (Gilbert, 1917). Later, during the early 20th century, gold dredging, channelization, sediment detention structures, and dams drastically altered channels, floodplains, and sediment budgets. The geomorphic recovery of these rivers during the early 20th century is poorly documented and less is known of the hydrologic and sedimentologic impacts of the debris dams, training walls, channelization, and channel incision that occurred during this period.

The Lower Yuba River (LYR) was at the center of hydraulic mining. Gilbert (1917) raised global awareness of the Yuba River to geomorphologists with his genius for quantifying large-scale complex phenomena to recognize fundamental relationships. Gilbert (1917) computed a watershed-scale sediment budget that demonstrated the over-whelming magnitude of hydraulic mining sediment introduced to the major rivers flowing out of the northwestern Sierra Nevada into the Sacramento Valley (the American, Bear, Yuba, and Feather Rivers). His computations show that approximately 1.1×10^9 m^3 of sediment was produced by hydraulic mining from the 1850s to ca. 1907, that almost half (523×10^6 m^3) of the sediment was produced in the Yuba basin, and that approximately half of that sediment produced in the Yuba basin was stored along the LYR at the time of his writing. Gilbert provides an excellent snap-shot of broad-scale conditions of the LYR at the turn of the 20th century and the dynamics leading up to that point. Much subsequent work has been done at smaller spatial scales, but limited study has been devoted to broader geographic or historical time scales.

Recent realization of the presence of abundant mercury in the gold-mining sediment constrains management possibilities for the LYR. Mercury was not native to watersheds of the Sierra Nevada in appreciable concentrations, but was introduced by 19th century gold miners in great quantities. Sedimentological studies show elemental mercury concentrations on the order of 400 ppb are common in the hydraulic mining sediment, which is stored in great quantities along the LYR (James et al., 2009). General policies of river management for this system must consider the need to contain this sediment rather than allowing lateral channel migration or floodplain scour to remobilize the mercury. Maintenance and management of the LYR have become goals for developing an integrated river management policy that includes flood control, improvement of ecological habitat, and water quality. Geomorphic elements are being considered increasingly in river rehabilitation studies and flexible criteria are emerging for assessing the potential for river rehabilitation (Brierley and Fryirs, 2000). River geomorphic history is essential to understanding (1) locations and character of fluvial features and (2) diverse potential trajectories of change that should be contemplated to achieve these goals.

2 HISTORICAL MORPHOGENESIS OF THE LYR FLOODPLAIN AND CHANNEL

Distinct geographic patterns and sedimentological features are recognized in the LYR that relate directly to historical changes to the LYR. These patterns include floodplain and historical terrace soils and topography, current and former positions of levees and debris dams, a high, largely abandoned channel system on the historical terrace, channel lateral planation, and appearance of channel protection. Some of these features, such as high-water channels have been related to sediment characteristics and the distribution of mercury. Many channel features have been located on and dated by historical maps. Many historical aerial photographs of the LYR between the 1930s and 1990 were scanned and rectified for historical reconstructions. Channel and floodplain features on photographs are identified and related to historical structures and geomorphic events. In some cases, the timing of river incision can be inferred from identifiable features. For example, weirs and dredge spoils were used initially to control flows to the high-water channels. Later increasing agricultural activity reveals decreasing frequencies of flooding on the historical terrace as the main channel incised. Similarly, early wing dams constructed along the main-channel margin were strategically located to prevent channels from reoccupying the high-water channels and represent early river management practices aimed at converting the braided floodplain back to a single thread channel system. These forms of evidence along with occasional historical cross-section and long-profile surveys help to constrain the timing of main-channel incision and abandonment of the braid-bar complex to a high terrace.

TRAJECTORIES OF FLUVIAL RECOVERY

A variety of general trajectories can be considered for recovery of the LYR system from aggradation and other 19th century and early 20th century disruptions (Table 1). One scenario would be to do nothing; that is, leave all engineering and control structures as they are and let the system adjust naturally to the current water and sediment loads. Repair and maintenance of structures, such as Daguerre Point Dam and the training walls associated with it, may be considered to be a variety of this approach. Another variant could be to let these structures fall into disrepair and let the river go natural entirely. A second scenario is to remove engineering controls. Removing or letting sediment detention structures fail in the LYR, such as Daguerre Point Dam, would not be viable without an alternative method of detaining the mercury laden sediment. In many alluvial rivers, hard engineering (Scenario 3) is to be avoided, but in this case mercury contamination of mining sediment, which forms the bulk of alluvium along the LYR, suggests that more, rather than less, bank protection may be needed. More documentation is needed of the concentrations and spatial distribution of mercury and the degree to which it is methylated or has the potential to methylate downstream. It appears that alluvium composed of mining sediment in the LYR is consistently contaminated with mercury, and that mining sediment is ubiquitous, so styles of river rehabilitation are severely limited.

Table 1. Potential trajectories for LYR channel and floodplain recovery

1. Passive restoration. Leave the system alone and let nature take its course.
2. Passive restoration with removal of engineering controls in the LYR.
3. Active restoration with removal of hard-engineered controls; i.e., channel liberté.
4. Active restoration with hard-engineered channel controls.

A wild card in the consideration of possible trajectories is recent incision of the Feather River channel bed at Shanghai Shoals below the mouth of the LYR. The shoals was formed on a resistant pedogenic clay over which the Feather River had been diverted in the early 19th century by cutting off a high-amplitude meander bend (James et al., 2009). About 3 km above the shoals and 2 km below the confluence of the Yuba and Feather Rivers, tree stumps rooted in the bed and inundated by ~0.5 m at Feather River low flows were carbon-dated to the late 19th century (James et al. 2009). This indicates that the pre-disturbance low-flow channel was probably a couple meters below its present level and that the shoals have imposed a base-level control that prevented channels from incising back to pre-mining elevations in the confluence area. The shoals were recently breached, however, which will likely lower base levels and initiate a period of active channel incision and mining sediment remobilization that could propagate up the LYR and Feather River. This potential trajectory reinforces the rationale for maintaining bank protection in the LYR.

CONCLUSION

River geomorphic histories can be complex and anecdotal but they are important to consider in the management of large rivers with substantial amounts of historical change. Identifying past channel conditions and positions is likely to lead to recognition of the nature and location of geomorphic forms, soil and sediment characteristics, habitat potential, toxic materials, archaeological sites, or other important features. Identifying past trajectories will also be instructive, although extrapolation of past trends into the future may not be valid. Instead, multiple potential future trajectories should be considered in the planning process in conjunction with knowledge of the geomorphic history unique to that river. It is often desirable to assess the geomorphic river condition for rehabilitation potential. In the case of the entrenched LYR, the potential to widen the meander belt is severely limited by mercury with the sediment stored in high historical terraces.

LIST OF REFERENCES

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