Using LiDAR and spatial modeling to map mine tailings in the Sierra Nevada, California

Utilisation du LiDAR et de la modélisation spatiale pour cartographier les sédiments miniers dans la Sierra Nevada, en Californie

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RÉSUMÉ

Les rivières de l'est de la Vallée de Sacramento ont été sévèrement remplies par les sédiments miniers hydrauliques (HMS) à la fin du XIXe siècle. Il en est résulté une persistance de la trajectoire géomorphologique de fortes charges de sédiments contaminés par le mercure. Au début du 20ème siècle, l'adaptation de la gestion en fonction des sédiments a entraîné la construction de barrages dans les montagnes pour empêcher les HMS d'atteindre la vallée de Sacramento. Compte tenu de la longévité limitée des barrages, ces dépôts de HMS poseront inévitablement un problème croissant en aval dans la rivière Sacramento et dans la baie de San Francisco. Plus récemment, les gestionnaires des rivières ont réalisé que les sédiments miniers contiennent de fortes concentrations de mercure et que les gisements de montagne doivent être identifiés, cartographiés, et stabilisés. Malheureusement, les emplacements et les volumes de HMS dans les montagnes sont mal connus. Cette étude utilise la modélisation spatiale de données topographiques LiDAR récentes pour identifier, cartographier, et calculer des volumes de dépôts de HMS dans les vallées de la Sierra Nevada près des mines hydrauliques. En raison de l'énormité et de la complexité des dépôts de HMS, l'accent est mis sur le développement de méthodes réalisables pour construire deux budgets sur les sédiments, pour les sites sélectionnés, l'un au moment de l'aggradation maximale et l'autre pour le présent.

ABSTRACT

Rivers in the eastern Sacramento Valley were severely aggraded by hydraulic mining sediment (HMS) in the late 19th century. This established a persistent geomorphic trajectory with regard to high loads of sediment contaminated by mercury. In the early 20th century, management adaptations to sedimentation involved construction of dams in the mountains to prevent HMS from reaching the Sacramento Valley. Given the finite longevity of dams, these HMS deposits will inevitably pose a growing problem downstream in the Sacramento River and the San Francisco Bay. Recently, river managers realized that HMS has high concentrations of mercury and that the mountain deposits need to be identified, mapped, and stabilized. Unfortunately, locations and volumes of HMS in the mountains are poorly known. This study uses spatial modeling of recent LiDAR topographic data to identify, map, and compute volumes of HMS deposits in valleys of the Sierra Nevada near the hydraulic mines. Due to the enormity and complexity of the HMS deposits, the focus is on developing feasible methods to construct two sediment budgets for selected sites; one at the time of maximum aggradation and another for the present time.

KEYWORDS

Geomorphology, mapping, anthropogenic sediment, remote sensing, sediment budgets

1 INTRODUCTION

Mid- to late-19th century hydraulic mining produced approximately 1.2 billion m^3 of hydraulic mining sediment (HMS) in the Sierra Nevada of California. Much of this sediment was delivered to the Yuba and Bear Rivers, major tributaries of the Sacramento River, which aggraded and experienced increased flood risks. Early studies of the HMS (Turner, 1891) documented the overall magnitude of this giant sediment slug and Gilbert's (1917) brilliant monograph produced initial sediment budgets (James et al., 2017). Little subsequent government research on HMS storage in the mountains was done after Gilbert's work due to the erroneous assumption that dams will prevent deliveries of HMS to the Sacramento Valley *ad infinitum*. The construction of dams in main channels below the mines from 1928 through the 1960s largely arrested the down-valley movement of HMS coming out of the mountains, but these dams have finite life expectancies. For example, Englebright Reservoir was built 85 m high on the lower Yuba River as a debris control structure with 86.3×10^6 m^3 of storage in 1941 and is more than 75 years old (NIDID, 2016). Combie Dam was built 30 m high on the middle Bear River with 6.8×10^6 m^3 of storage in 1928 and is more than 85 years old. The importance of HMS storage in the mountains was down-played until recent realizations of high concentrations of mercury in the HMS led to renewed interest in the amount of HMS stored in the upper basins. Initial studies have largely focused on small detention dams designed to retain HMS generated during a late period of licensed mining. By mapping and computing sediment volumes in large terrace and tailing-fan deposits in the mountains, this study examines the importance of storage of HMS behind small dams relatively to storage along channels.

2 METHODS

Volumes of HMS produced in the early 19th century were approximated by plane-table mapping of selected large mines (Gilbert, 1917), but storage volumes remaining in the mountains were never accurately measured. This study uses airborne LiDAR to compute volumes of hydraulic mine pits and re-estimate 19th century HMS production in selected basins. It also uses geomorphometric methods to compute volumetric estimates of HMS storage at present and during the peak period of channel aggradation. HMS production volumes were measured by interpolating digital elevation models (DEMs) of pre-mining mine-pit topography and subtracting the modern DEM to compute a DEM of difference (DoD). The present storage volume of HMS in selected valley reaches was computed by creating a DEM of the bedrock valley topography—based on valley-bottom cross-sections and channel longitudinal profiles in unfilled valleys—and subtracting it from the modern DEM. The volume of HMS at the time of maximum aggradation was computed by adding the volume of material exhumed from the reach to the volume stored. The exhumed volume was determined by subtracting the modern DEM from a model DEM constructed by interpolation of the high terrace threads (Figure 1).

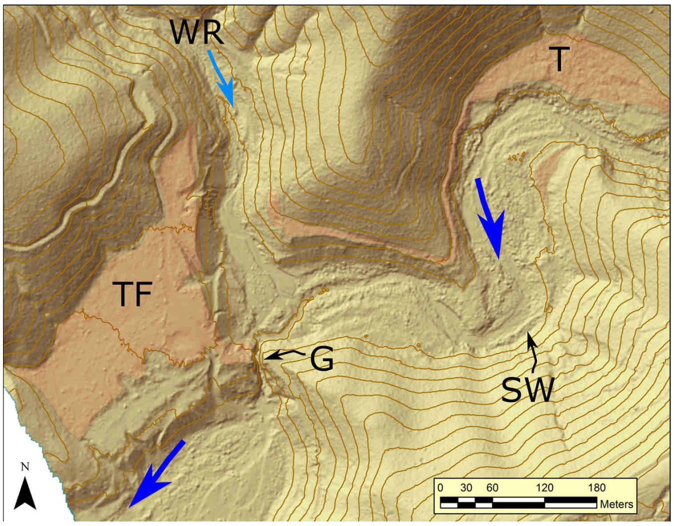

Figure 1. A tailings fan (TF) from Wilcox Ravine (WR) dammed Steephollow Creek (large blue arrows) resulting in slackwater (SW) deposits above the dam, terrace threads (T) that slope upstream, and formation of a gorge (G) where the main channel later cut across a bedrock spur. Volumes of sediment stored in this area were measured by geomorphometric methods.

3 RESULTS AND DISCUSSION

Preliminary results suggest that Gilbert's (1917) volumetric estimates of HMS production for some the largest mines differed somewhat from what can now be estimated more accurately from LiDAR imagery. Gilbert interpolated planar pre-mining surfaces from rim to rim across the mine pits, so volumes tended to be overestimated for mines that cut into low, pre-existing drainages and were underestimated where mines cut into ridge tops. Gilbert's HMS production estimates grouped some mines and did not include many small mines. This pilot study does not compute total volumes of production for entire catchments, but preliminary results suggest that the recalculated volumes are approximately consistent with Gilbert's net volumes of sediment production. However, the revised measurements improve resolutions and accuracies of the spatial distribution of HMS production.

Large volumes of HMS were deposited locally near the mines. Much of this sediment remains stored in fan and terrace deposits that are much larger than deposits behind relatively small dams constructed later on tributaries to detain HMS from 20th century mining. This toxic sediment is an immediate threat to ecosystems and public health in the mountains and is being remobilized and stored in major reservoirs downstream. Ultimately, HMS will pose a threat to aquatic systems in the Sacramento Valley when the larger reservoirs cease to function.

4 CONCLUSIONS

More than a billion m^3 of HMS was produced in the Sierra Nevada during the 19th century and a large amount of that sediment remains in the mountains. Mapping and computing sediment volumes in large terrace and tailing-fan deposits near the mines, demonstrates that storage behind small dams is a relatively small proportion of the sediment budget at some sites. This sediment is presently prevented from reaching the Sacramento Valley, Sacramento-San Joaquin Delta, and San Francisco Bay by a series of moderate-sized, aging dams. Mercury contamination of the HMS poses a dire threat to water quality, aquatic ecosystems, and public health in the mountains now, but given the finite longevity of dams, these vast deposits represent an inevitable problem downstream.

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