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Effects of rapid urbanization on streamflow, erosion, and sedimentation in a desert stream in the American Southwest

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ABSTRACT

Rapid urbanization has resulted in a series of sequential effects on a desert stream in the American Southwest. Lower Las Vegas Wash was a dry wash characterized by infrequent flood deposition when Las Vegas, Nevada was established in 1905. Wastewater effluent was discharged into the wash in low volumes for over 3 decades. Wastewater volumes increased commensurably with accelerated population growth during the late 20th century and created a sequence of feedback effects on the floodplain. Initially slow saturation of the valley fill created a desert oasis of dense floodplain vegetation and wetlands. Annual streamflow began in 1958 and erosion began a decade later with shallow incision in discontinuous channel segments. Increasing baseflow gradually enlarged channels; headcutting was active during the 1970s to 1984. The incised channels concentrated storm runoff, which accelerated local channel erosion, and in 1984 the headcuts were integrated during a series of monsoon floods. Wetlands were drained and most floodplain vegetation destroyed. Channel erosion continued unabated until engineering interventions began in the 21st century. No natural channel recovery occurred after initial urbanization effects because streamflow never stabilized in the late 20th century. A 6.6 M m^3 sediment slug, eroded from the wash in ~25 years, was deposited in Las Vegas Bay in Lake Mead. Falling reservoir levels during the 21st century are responsible for sediment redistribution and infilling of the bay. Close monitoring of impacts is recommended when urban wastewater and storm runoff are discharged on a desert wash. Channel interventions, when necessary, are advised in order to prevent costly engineering schemes of channel stabilization, flood control, and floodplain restoration.

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1. Introduction

The effects of urbanization on watersheds are well documented and demonstrate extensive and permanent harm on fluvial systems. Interest in this field of study has created the new sub-discipline of urban hydrology (Akan and Houghtalen, 2003). On all scales from creeks to rivers, the human effects on local watersheds have resulted in dramatic physical impacts (Chin et al., 2013a,b). The study of urbanization and river channels has progressed to a point where we understand how the geographic setting, climate, and geology of a given area predicate specific types of system responses to a single stressor (Gregory, 2006); however, our current understanding and assessment of urbanization in arid regions is less well understood than in humid and temperate regions (Chin, 2006). Stream response is dependent on the nature of change to inputs and the character of streams (James and Lecce, 2013). Arid environments are characterized by less predictable climate-driven processes, have sensitive vegetation-poor landscapes, and are strongly impacted by infrequent, high magnitude events (Wolman and Gerson, 1978).

In this study we discuss the effects of urban growth and development on a dry desert wash in the arid–semiarid region of Las Vegas Valley in southern Nevada. The rapid urbanization of the Las Vegas metropolitan area provides a case study of feedback effects on a dryland stream. Drylands occupy about 40% of the land surface and one third of the world's population lives there (Le Houérou, 2002). As in other global environments, population growth in arid regions is concentrated in cities (Buharg and Urdal, 2013). In the Middle East and North Africa, for example, urban population ranges from 85% to 92% and growth rates are among the fastest in the world. The effects of desert cities on scarce water

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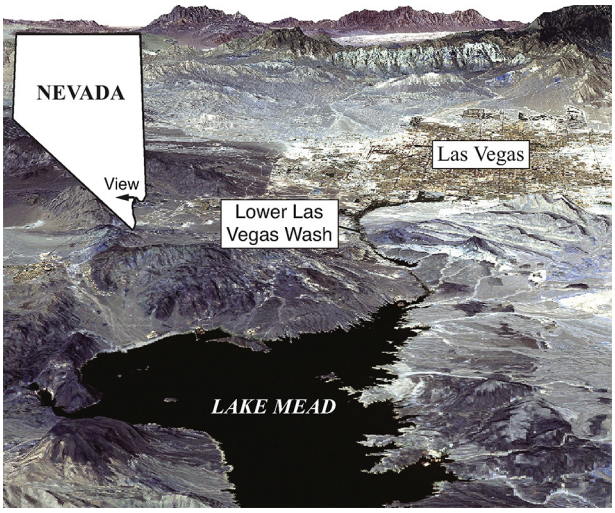

Fig. 1. Las Vegas Valley and adjacent mountains in southern Nevada. Lower Las Vegas Wash flows eastward from the city of Las Vegas into Lake Mead. This scene is a Landsat 1992^{TM} image draped onto a USGS 90 m resolution DEM.

resources, combined with the less predictable nature of desert processes, create challenges for urban managers in arid lands. The experience of rapid growth in Las Vegas Valley and management of its wastewater effluent and storm runoff may serve as a useful example for other arid region cities. Consequent channel and floodplain degradation described in our study resulted in expensive societal costs that included channel stabilization, restoration of wetlands, urban flood control, and replacement of infrastructure (roads, bridges, pipelines, marina, etc.). Such costs might not be reasonably borne by communities and agencies in other parts of the arid world. Avoiding similar future problems elsewhere on the basis of the Las Vegas example would have substantial value.

Three aspects of this area are unique for study of effects of urbanization on a fluvial system. (1) The pre-settlement environmental condition of Lower Las Vegas Wash is revealed in deep valley-fill exposures. (2) The principal effect of urbanization is the population-driven, wastewater effluent discharged on a previously dry wash. (3) A massive sediment slug was deposited into Lake Mead in response to 20th century erosion.

The city of Las Vegas and surrounding Clark County, internationally known as an entertainment and vacation destination, experienced dramatic growth during the last quarter of the 20th century and first decade of the 21st century. The metropolis is located in the wide Las Vegas Valley, an arid-to-semi-arid drainage basin surrounded by rugged mountain ranges. Lower Las Vegas Wash (LLVW) drains most of the open valley and flows ~11 km eastward into Las Vegas Bay in Lake Mead (Fig. 1). LLVW originated as a headward-cutting tributary of the Colorado River that followed a fault zone along the north end of the volcanic River Mountains (Fig. 2) and captured the topographically closed Las Vegas Valley drainage about 3–4 million years ago (Longwell et al., 1965). Stream terraces in the wash preserve evidence of several cycles of valley cutting and filling in response to Quaternary climate changes (Lundstrom et al., 2008). Before urbanization of Las Vegas Valley the drainage system was composed of a few natural springs and marshes (Las Vegas is Spanish for the meadows) and a natural system of coalescing dry washes that drained into LLVW, which conveyed storm runoff to the Colorado River.

The goal of this study is to interpret the interactions between urban developments in a rapidly growing arid setting, resultant changes in groundwater and runoff in a pre-existing drainage, massive erosion, and downstream sedimentation. These changes to Lower Las Vegas Wash resulted from a series of feedback effects related to the primary impact of consistently increasing population: consistently increasing volumes of wastewater and urban/storm runoff with time. The overall research question in this study is to determine the effects of urbanization on a desert stream valley. More specifically, how do the pre-settlement alluvial processes differ from population-driven streamflow? What are the roles of wastewater baseflow and storm runoff in the degradation and erosion of the floodplain? And what impact, if any, does short-term climate change have on this urban stream? We also calculated the volume of sediment deposited into Lake Mead reservoir, and we present a short summary on the coordinated governmental responses to late 20th century erosion in the wash.

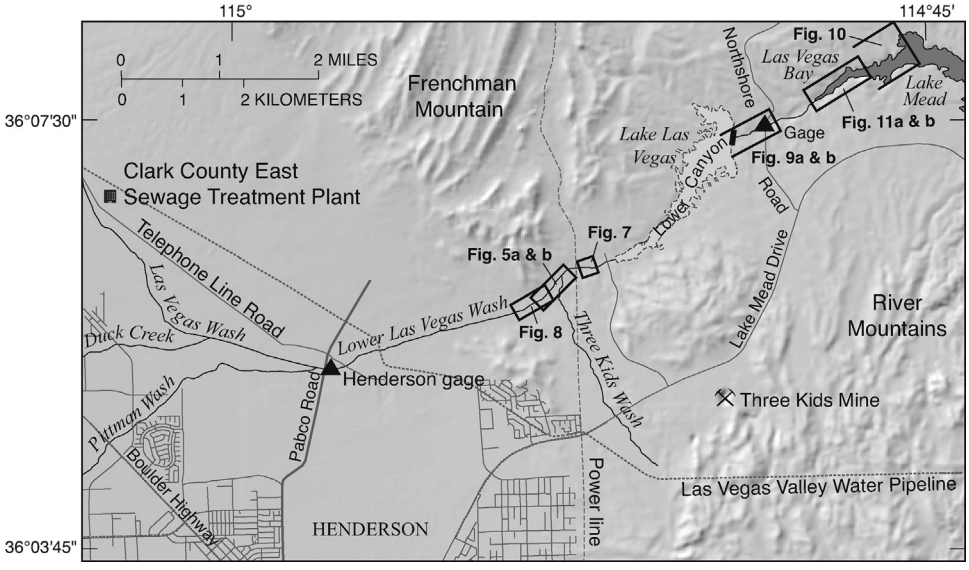

Fig. 2. 20th century map of Lower Las Vegas Wash showing Henderson and Northshore Road stream gages and location of several figures.