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Ground-Water Recharge From Small Intermittent Streams in the Western Mojave Desert, California

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Abstract

Population growth has impacted ground-water resources in the western Mojave Desert, where declining water levels suggest that recharge rates have not kept pace with withdrawals. Recharge from the Mojave River, the largest hydrographic feature in the study area, is relatively well characterized. In contrast, recharge from numerous smaller streams that convey runoff from the bounding mountains is poorly characterized. The current study examined four representative streams to assess recharge from these intermittent sources. Hydraulic, thermal, geomorphic, chemical, and isotopic data were used to study recharge processes, from streamflow generation and infiltration to percolation through the unsaturated zone. Ground-water movement away from recharge areas was also assessed.

Infiltration in amounts sufficient to have a measurable effect on subsurface temperature profiles did not occur in every year in instrumented study reaches. In addition to streamflow availability, results showed the importance of sediment texture in controlling infiltration and eventual recharge. Infiltration amounts of about 0.7 meters per year were an approximate threshold for the occurrence of ground-water recharge. Estimated travel times through the thick unsaturated zones underlying channels reached several hundred years. Recharging fluxes were influenced by stratigraphic complexity and depositional dynamics. Because of channel meandering, not all water that penetrates beneath the root zone can be assumed to become recharge on active alluvial fans.

Away from study washes, elevated chloride concentrations and highly negative water potentials beneath the root zone indicated negligible recharge from direct infiltration of precipitation under current climatic conditions. In upstream portions of washes, generally low subsurface chloride concentrations and near-zero water potentials indicated downward movement of water toward the water table, driven primarily by gravity. Recharging conditions did not extend to the distal ends of all washes. Where urbanization had concentrated spatially distributed runoff into a small number of fixed channels, enhanced infiltration induced recharging conditions, mobilizing accumulated chloride.

Estimated amounts of ground-water recharge from the studied reaches were small. Extrapolating on the basis of drainage areas, the estimated aggregate recharge from small intermittent streams is minor compared to recharge from the Mojave River. Recharge is largely controlled by streamflow availability, which primarily reflects precipitation patterns. Precipitation in the Mojave Desert is strongly controlled by topography. Cool moist air masses from the Pacific Ocean are mostly blocked from entering the desert by the high mountains bordering its southern edge. Storms do, however, readily enter the region through Cajon Pass. These storms generate flow in the Mojave River that often reaches Afton Canyon, more than 150 kilometers downstream. The isotopic composition of ground water reflects the localization of recharge beneath the Mojave River. Similar processes occur near San Gorgonio Pass, 75 kilometers southeast from Cajon Pass along the bounding San Andreas Fault.

Introduction

The western Mojave Desert east of Los Angeles (fig. 1) is arid with hot, dry summers and cold winters. The population of the area, including the Palmdale/Lancaster areas to the west, the Victorville area, and the Yucca Valley area to the east, has increased rapidly from about 500,000 in 1990 to almost 670,000 in 2000 (California Department of Finance, 2002a,b). Water supply is derived almost entirely from ground water, and pumping has increased with population. As a result of pumping in excess of recharge, water levels throughout the area have declined in recent years (Smith, 2003; Stamos and others, 2001; Mendez and Christensen, 1997; Stamos and Predmore, 1995). Declining water levels and increased competition for ground-water supplies has resulted in a series of lawsuits and adjudications of parts of the area along the Mojave River (California Supreme Court, 2000) and in Yucca Valley (California Superior Court, 1977).

A better understanding of the physical processes that control the spatial and temporal distribution of natural recharge may help resolve questions about ground-water availability and enable agencies responsible for water supply to better manage ground-water resources. Ground-water recharge from larger streams such as the Mojave River has great economic value and has been extensively studied by traditional methods

a result, flow in the wash has followed nearly the same course, repeatedly wetting the underlying unsaturated zone, since incision of the wash after development of Cajon Pass, about 500,000 years ago (Meisling and Weldon, 1989). This repeated wetting has prevented development of the thick, impermeable caliche layers that underlie the alluvial fan away from the wash (Izbicki and others, 2000b, 2002). The bed of the wash is composed of sand along its entire length. Infiltration rates measured as part of this study by using a 1.2-m-diameter double-ring infiltrometer ranged from 1.3×10^{-2} to 2.2×10^{-2} cm/s (0.46–0.79 m/hr; table 2). Infiltration rates were lower near Cajon Pass and higher farther downstream.

The unsaturated zone underlying Oro Grande Wash ranges from more than 300-m thick near Cajon Pass to about 130 m along the downstream parts of the study reach. The alluvial deposits are composed of younger deposits of sand and gravel, reworked from the surrounding Victorville fan, that partly backfills the incision of the wash to a depth of about 7 m. These deposits are surrounded and underlain by older deposits of the Victorville fan (Meisling and Weldon, 1989) that consist of alternating layers of fluvially sorted sand, silt, and clay, with smaller amounts of gravel (Izbicki and others 2000a,b; Izbicki, 2002). The younger deposits are highly permeable, with saturated hydraulic conductivities of about 5.5×10^{-3} cm/s (Izbicki, 2002). The Victorville fan deposits are less permeable, and the saturated hydraulic conductivity of core material collected from the unsaturated zone along downstream reaches of Oro Grande Wash near instrumented borehole VVWD ranged from about 7×10^{-4} to 4×10^{-6} cm/s (fig. 5). Areally extensive clay layers having an average thickness of 1.2 m, but often less than 0.3 m thick, are present within the deeper, older deposits. These lower permeability layers are believed to be buried soil horizons (paleosols; Izbicki, 2002; fig. 6). They have lower permeability that impedes the downward movement of water and increases the lateral movement of water away from the wash (Izbicki, 2002; Nimmo and others, 2002). The statistical distribution of the low-permeability materials in the unsaturated zone along the downstream reaches of Oro Grande Wash was described by Izbicki (2002), and the effect of particle-size and sorting within the older deposits on unsaturated hydraulic properties was described by Winfield (2000).

Sheep Creek Wash

Sheep Creek Wash drains 36.8 km² in the San Gabriel Mountains west of Cajon Pass (fig. 3). The conical shape of the alluvial fan underlying the wash directs runoff away from the active channel of the wash (fig. 4), and the drainage area along the 18.8-km study reach from the mountain front to the downstream measurement site is only 2.4 km². Sheep Creek flows intermittently as a result of runoff from the higher altitudes in the mountains. Precipitation at the higher altitudes of the San Gabriel Mountains averages more then 1,000 mm/yr, with much of the precipitation falling as snow during the winter months. Precipitation decreases away from the mountain front and in most years is less than 150 mm/y along the downstream parts of the study reach.

On the basis of a relation between channel geometry and streamflow data (Lines, 1996), average annual flow in Sheep Creek Wash near the mountain front is estimated to be about 3.1 hm³ (table 1). In some years, sustained flows, lasting as long as several weeks, may occur near the mountain front as a result of snowmelt after wet winters. The bank-to-bank width of the wash ranges from about 80 m near the mountain front to about 3 m as flows decrease downstream. Most flows near the mountain front do not fill the entire channel, and thus the active channel is much narrower. Under predevelopment conditions, streamflow in Sheep Creek Wash did not necessarily follow the same course each year; and occasionally flowed in different channels in response to deposition and subsequent changes in the slope of the fan (fig. 4). As a result, flow in Sheep Creek Wash did not repeatedly wet the same material year after year in the same manner as did flow in Oro Grande Wash (Izbicki and others, 2002). In recent years, a series of levees has restricted streamflow to fewer active channels. Near the mountain front the bed of the wash is composed of boulders and cobbles in a matrix of silt and sand. Farther downstream the bed of the wash is composed of fine silt. Infiltration rates measured as part of this study by using a 1.2-m-diameter double-ring infiltrometer ranged from 0.1×10^{-2} to 0.4×10^{-2} cm/s (0.04–0.14 m/hr; table 2). Infiltration rates were higher near the mountain front and lower farther downstream.

The thickness of the unsaturated zone underlying the wash ranges from more than 300 m near the mountain front to about 150 m along the downstream parts of the study reach (Izbicki and others, 2002). Much of the alluvial material comprising the Sheep Creek fan was deposited by debris flows and is poorly sorted. Near the mountain front, the deposits are composed of cobbles and gravel in a matrix of coarse sand. Although some cobbles and gravels are present in the deposits farther from the mountain front, the deposits there are finer grained and the matrix is composed of silt. Deposition on the Sheep Creek fan must have been fairly rapid and continuous, as evidence of paleosols within the deposits was not observed in test-drilling logs collected by Izbicki and others (1995, 2000a). Although the saturated hydraulic conductivity of the unsaturated deposits was not measured as part of this study, Winfield (2000) measured the physical properties, sorting, and water-retention characteristics. Winfield (2000) determined that differences in the water-retention characteristics between debris-flow deposits underlying Sheep Creek Wash and fluvially sorted deposits underlying Oro Grande Wash were determined primarily by the particle-size distribution of the material and not by a lack of fluvial sorting prior to deposition.

Big Rock Creek

Big Rock Creek drains 108 km² in the San Gabriel Mountains to the west of the Mojave River Basin in Antelope