Journal of Hydrology 369 (2009) 30–43

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Interbasin flow in the Great Basin with special reference to the southern Funeral Mountains and the source of Furnace Creek springs, Death Valley, California, U.S.

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ARTICLE INFO

Article history:
Received 1 May 2008
Received in revised form 5 February 2009
Accepted 5 February 2009

This manuscript was handled by P. Baveye, Editor-in-Chief, with the assistance of Susan S. Hubbard, Associate Editor

Keywords:
Death Valley
Hydrochemistry
Springs
Ground-water flow
Ground-water recharge

SUMMARY

Interbasin flow in the Great Basin has been established by scientific studies during the past century. While not occurring uniformly between all basins, its occurrence is common and is a function of the hydraulic gradient between basins and hydraulic conductivity of the intervening rocks. The Furnace Creek springs in Death Valley, California are an example of large volume springs that are widely accepted as being the discharge points of regional interbasin flow. The flow path has been interpreted historically to be through consolidated Paleozoic carbonate rocks in the southern Funeral Mountains.

This work reviews the preponderance of evidence supporting the concept of interbasin flow in the Death Valley region and the Great Basin and addresses the conceptual model of pluvial and recent recharge [Nelson, S.T., Anderson, K., Mayo, A.L., 2004. Testing the interbasin flow hypothesis at Death Valley, California. EOS 85, 349; Anderson, K., Nelson, S., Mayo, A., Tingey, D., 2006. Interbasin flow revisited: the contribution of local recharge to high-discharge springs, Death Valley, California. Journal of Hydrology 323, 276–302] as the source of the Furnace Creek springs. We find that there is insufficient modern recharge and insufficient storage potential and permeability within the basin-fill units in the Furnace Creek basin for these to serve as a local aquifer. Further, the lack of high sulfate content in the spring waters argues against significant flow through basin-fill sediments and instead suggests flow through underlying consolidated carbonate rocks. The maximum temperature of the spring discharge appears to require deep circulation through consolidated rocks; the Tertiary basin fill is of insufficient thickness to generate such temperatures as a result of local fluid circulation. Finally, the stable isotope data and chemical mass balance modeling actually support the interbasin flow conceptual model rather than the alternative presented in Nelson et al. [Nelson, S.T., Anderson, K., Mayo, A.L., 2004. Testing the interbasin flow hypothesis at Death Valley, California. EOS 85, 349] and Anderson et al. [Anderson, K., Nelson, S., Mayo, A., Tingey, D., 2006. Interbasin flow revisited: the contribution of local recharge to high-discharge springs, Death Valley, California. Journal of Hydrology 323, 276–302]. In light of these inconsistencies, interbasin flow is the only readily apparent explanation for the large spring discharges at Furnace Creek and, in our view, is the likely explanation for most large volume, low elevation springs in the Great Basin. An understanding of hydrogeologic processes that control the rate and direction of ground-water flow in eastern and central Nevada is necessary component of regional water-resource planning and management of alluvial and bedrock aquifers.

Introduction

Interbasin flow (ground-water flow between ground-water basins through bedrock mountain ranges) in the Great Basin has been established by scientific studies during the past century (Eakin, 1966; Winograd and Thordarson, 1975; Harrill et al., 1988). Interbasin flow, though it does not occur uniformly between all basins, occurs commonly and is a function of the hydraulic gradient between basins and hydraulic conductivity of the intervening rocks. The Furnace Creek springs (Texas, Travertine, and Nevares Springs) in Death Valley, California are examples of large volume springs (flow rates greater than 1000 m^3/day [700 L/min]) in the Great Basin which have been widely accepted as being the discharge points of regional interbasin flow. Early investigators (Hunt and Robinson,

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0022-1694/$ - see front matter Published by Elsevier B.V.
doi:10.1016/j.jhydrol.2009.02.048

1960; Miller, 1977) concluded the spring flow was derived from interbasin flow because of insufficient local recharge to support the flow of the springs. The path of waters that ultimately discharge at the Furnace Creek springs has been interpreted to be through consolidated Paleozoic carbonate rocks in the southern Funeral Mountains, based on similar chemical and isotopic characteristics of the ground-water in carbonate rocks at Ash Meadows, Nevada, about 50 km to the east (Fig. 1) (Hunt and Robinson, 1960; Winograd and Thordarson, 1975; Steinkampf and Werrell, 2001). Recent papers by Nelson et al. (2004) and Anderson et al. (2006), although not denying the existence of interbasin flow, vigorously challenge it as widely occurring phenomena; these authors suggest that the large volume springs that issue near the mouth of Furnace Creek in Death Valley (Fig. 1) derive their source largely from recharge that occurred during the Pleistocene with a small percentage of modern recharge.

Knowledge of basin water balances and the magnitude of interbasin ground-water flow is the basis for regional ground-water management and water-resource planning in the Great Basin of Nevada (Scott et al., 1971). Rapid population growth, arid conditions, and high water use have caused extensive development of available water resources. Ground-water use in some alluvial-fill basins has resulted in ground-water mining and subsidence; adjacent bedrock aquifers are increasingly being targeted for large-scale development. Such development may potentially impact local and regional water quantity and quality, existing water rights, and sensitive wildlife habitats. An understanding of hydrogeologic processes that control the rate and direction of ground-water flow in eastern and central Nevada is necessary in assessing the potential impacts of any proposed large-scale ground-water development. On a more local scale, an understanding of the magnitude of interbasin flow in southern Nevada is a critical part of defining ground-water flow paths and travel times associated with potential movement of radioactive material from the Nevada Test Site and to the characterization of the ground-water system in the vicinity of the proposed high-level radioactive waste repository at Yucca Mountain, Nevada (Hanks et al., 1999).

In this article the concept of interbasin flow in the Great Basin is revisited, using the large volume springs at Death Valley, California, as a particularly relevant example. The conceptual model of the source of Furnace Creek springs is reviewed by examining the geology and structure of the Funeral Mountains, the hydrology and geology of the basin-fill deposits of the Furnace Creek basin, and the isotope and solute geochemistry of the spring discharge and potential sources. This article also assesses the validity of recent work (Nelson et al., 2004; Anderson et al., 2006) postulating that the spring flows are the result of locally-derived and Pleistocene recharge, rather than interbasin flow.

Geologic setting of the Furnace Creek springs and surrounding region

The Furnace Creek springs and surrounding areas are located at the southern end of the Great Basin carbonate-rock province. The thickness of Paleozoic carbonate rocks in the province is as much as 8 km and form the major regional consolidated-rock aquifer in the eastern two-thirds of the Great Basin (Winograd and Thordarson, 1975; Bedinger et al., 1989a; Dettinger et al., 1995; Dettinger and Schaefer, 1996; D'Agnese et al., 1997; Harrill and Prudic, 1998). Large hydraulic conductivities are reported for carbonate rocks of this aquifer and result from a combination of fractures, faults, and solution channels (Winograd and Thordarson, 1975; Bedinger et al., 1989b; Belcher et al., 2001). Hydraulic tests of carbonate-rock aquifers throughout eastern and southern Nevada indicate that faults can increase the carbonate-rock transmissivity by a factor of 25 or more (Dettinger et al., 1995). Most of the large volume springs in the province are associated with the carbonate rocks, in some cases issuing directly from the carbonate rocks, such as Nevares Spring in the Furnace Creek area and Point of Rocks Spring in the Ash Meadows area (Winograd and Thordarson, 1975; Steinkampf and Werrell, 2001) (Figs. 1 and 2).

The southern Funeral Mountains are an uplifted block of Cambrian through Mississippian predominantly carbonate rocks up to 4-km thick overlying a similar thickness of Lower Cambrian to Late Proterozoic predominantly siliciclastic rocks (Cemen et al., 1985; McAllister, 1970; Fridrich et al., 2003a). The Furnace Creek fault zone, a major right-lateral strike-slip fault, bounds the range on the southwest and separates it from the Furnace Creek basin to the south (Fig. 2). The inactive Furnace Creek fault zone intersects the active northern Death Valley fault zone near the Furnace Creek springs in Death Valley (Workman et al., 2002). The southern Funeral Mountains block is bounded on the northeast by the Pahrump–Stewart Valley fault, another right-lateral strike-slip fault. Within the Funeral Mountains, carbonate rocks are truncated to the northwest by Late Proterozoic siliciclastic rocks carried in the upper plate of the Mesozoic Schwaub Peak thrust (Figs. 2 and 3). Farther to the northwest, Middle and Late Proterozoic metamorphic rocks are exposed (Workman et al., 2002) (Fig. 2). Paleozoic bedrock in the southern Funeral Mountains dips to the southeast and is disrupted by at least three major low-angle normal faults and a multitude of closely spaced, smaller-offset faults that strike in a wide range of directions, and that form a continuous network of secondary fractures (Fig. 3). Paleozoic carbonate rocks crop out in the southern Funeral Mountains and in the ranges bounding the east side of the Amargosa Desert (Fig. 2); their presence beneath basin-fill sediments, however, is subject to interpretation. Paleozoic carbonate rocks have been identified in borehole UE–25 p#1 to the east of Yucca Mountain and in boreholes drilled in the northern, eastern, and western edges of the Amargosa Desert (Fig. 2); no deep boreholes penetrate into the Paleozoic rock underlying the thick Cenozoic sedimentary section in the center of the Amargosa Desert. Most workers agree that Paleozoic carbonate rocks are absent or severely attenuated south and west of the Furnace Creek fault zone (Stewart, 1983; Wright et al., 1991).

The Furnace Creek basin is a structural and depositional basin that is closely associated with the Furnace Creek fault zone (Wright et al., 1991, 1999) (Fig. 3). In the Furnace Creek basin, Cenozoic basin-fill rocks include older, synextensional sedimentary rocks that are folded, faulted, and intercalated with generally coeval volcanic rocks. This assemblage of older rocks is unconformably overlain by less-deformed, dominantly volcanic-free, post-tectonic alluvial sediments (Fig. 3). The basin fill consists from oldest to youngest, of the Artist Drive Formation, the Furnace Creek Formation, the Greenwater volcanics, and the Funeral Formation (Cemen et al., 1985; Greene, 1997; Wright et al., 1999) (Fig. 3). The Artist Drive and Furnace Creek Formations consist of poorly sorted fine- to coarse-grained bedded deposits, including fine-grained tuffaceous sedimentary rocks with bimodal (dacite-basalt) volcanic rocks (McAllister, 1970, 1973, 1974; Cemen et al., 1985; Wright et al., 1991; Greene, 1997). Gravelly beds are commonly in a mudstone matrix. Lacustrine mudstones and evaporites, including borates, gypsum, anhydrite and limestone occur in the Furnace Creek Formation. The Funeral Formation consists of poorly consolidated, coarse-grained alluvial material and basalt flows (Fig. 3).

The rocks of the southern Funeral Mountains and of the adjacent basins can be divided into four major hydrogeologic units, including two units in the consolidated pre-Cenozoic rocks and two units in the Cenozoic basin fill (Fig. 3). The deepest consoli-