Effects of Climate Change on Devils Hole and the Devils Hole Pupfish, *Cyprinodon diabolis*

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Figure 1. Devils Hole Pupfish. Photo courtesy of Tom Baugh

Figure 2. Devils Hole

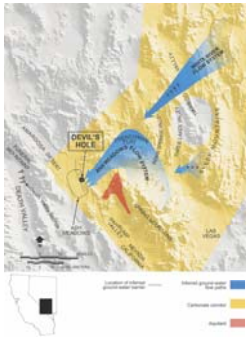

Figure 3. Groundwater flow into Devils Hole. From Riggs and Deacon 2004.

Devils Hole, Nye County Nevada, was designated as a disjunct portion of Death Valley National Monument (now Park) in 1952 by President Harry Truman "for the preservation of the unusual features of scenic, scientific, and educational interest therein contained." Among these unique features is the Devils Hole pupfish, *Cyprinodon diabolis* (Wales) an endemic fish with the most restricted distribution of any known vertebrate worldwide (figures 1 and 2).

Riggs and deacon (2004) described Devils Hole as "… a fissure, opened by regional tectonic extension of Paleozoic carbonate rocks, that acts, in concert with innumerable other similarly formed fissures, as a subterranean drainage network that transmits rain water and snowmelt, primarily from the relatively well-watered upper elevations of the Spring Mountains, to arid basin-floor spring-discharge oases" (figure 3). Smaller, but not insignificant quantities of water are contributed to the Ash Meadows flow system from the White River flow system and the Sheep Mountains. Any anthropogenic factors that alter the volume or temperature of the water in Devils Hole, particularly as it affects the spawning shelf, will undoubtedly impact Devils Hole pupfish.

To our knowledge estimates of the effect of climate change to Devils Hole specifically or the Mohave Desert in general has yet to be published. However, Seager et al. (2007) did asses the 19 climate models that attempt to predict changes to southwestern North America. They found broad consensus that the region will dry in the 21st century. They concluded "If these models are correct, the levels of aridity of the recent multiyear drought or the Dust Bowl, and the 1950s droughts will become the new climatology of the American Southwest within a time frame of years to decades."

Effects to Devils Hole and the endemic pupfish can be divided into two factors; temperature and water volume effects. These two impacts are neither independent nor mutually exclusive.

Water Temperature Effects

The presence of larvae year round suggests Devils Hole pupfish spawn throughout the year (Barrett, personal observation). Nevertheless increased larvae numbers in spring suggest peak spawning, or at least peak reproductive success, from February to May (Riggs and Deacon 2004). Pupfish spawning occurs almost exclusively on an approximately 15 m^2 area with water depths ranging from 0.17 to 0.68 m (Gustafson and Deacon 1998). Water in the deeper portion of Devils Hole is at a constant 33.5 to 35°C and above the physiological limits of oogenisis for congeneric pupfish (Shrode 1975, Shrode and Gerking 1977). Furthermore, preliminary results by Drs. Stan Hillyard and Frank Van Breukelen (Hillyard, personal communication) indicate temperatures of 31 °C and above are stressful to hybrid pupfish (*C n mionectes* x *C diabolis*) greater than 2 g. Indeed, at these temperatures pupfish often metabolize anaerobically while performing short bursts of activity. Currently minimum temperature over the inner shelf frequently dips below 29°C from October to April and diel variations of 31.5 to 35°C are not uncommon over the inner shelf, where midday temperatures may be elevated for 3 to 3 ½ hours during June and July (figure 4, Riggs and Deacon 2004). These cooler temperatures, albeit temporary, may be critical to successful spawning of Devils Hole pupfish. Increased temperature as predicted by Seager et al (2007) may raise both the upper and lower limits of water temperature on the spawning shelf. Because the fish are likely at their physiological limits to reproduction for much of the year, this could either shift or shorten the current period of peak spawning.

Oxygen concentration in Devils Hole waters further complicates the problems of physiological tolerance. Temperature effects reported by Hillyard and Van Breukelen (personal communication) and by Shrode (1975) and Shrode and Gerking (1977) were observed under experimental conditions in which temperatures were varied, but oxygen concentration was held constant at 100% saturation. Riggs and Deacon (2004) report relatively constant oxygen concentration of 2.3-2.6 mg/l (34-38% saturation) throughout most of the Devils Hole cavern. Periodic measurements of daily variation in oxygen concentration over the inner (stations 3 and 4), middle (station 2) and outer (station 1) portions of the shallow shelf were made by Deacon and others from UNLV from June 1974 through September 1995 (figure 5). These measurements demonstrate that daily variation in oxygen concentration becomes especially pronounced from April through September. Maximum oxygen levels typically occur from about noon to midafternoon, when they may approach 100% saturation over parts of the inner shelf for a few hours in May through September, seldom reach 100% over the middle shelf, and never get to that level over the outer shelf.

Energy inputs into Devils Hole vary seasonally (James 1969, Deacon and Deacon 1979, Blinn and Wilson 2005). Because Devils Hole lies in a narrow fissure approximately 17 m below the surrounding land surface, direct sunlight does not reach the water surface in the winter. It begins to reach the water in mid-February and increases to a maximum of four hours per day in June. It then begins to decrease and again fails to reach the water by late November. Energy from both direct and indirect or reflected light is photosynthetically fixed by filamentous green algae, cyanobacteria (bluegreen algae), and diatoms (Blinn and Wilson 2005). In addition to fixing autochthonous energy these algae benefit the pupfish by generating dissolved oxygen as a by product of photosynthesis. Deacon and Deacon (1979) found an approximately two-month lag time between increasing sunlight and increasing pupfish populations and an approximately one-month lag time between increases in primary productivity and increases in pupfish population. Currently during June and July the increased frequency and duration of high midday temperatures, coupled with diminishing photosynthetically induced rises in dissolved oxygen, make physiological compensation increasingly difficult and limit reproductive success. Because daily minimum temperatures are already challenging physiological limits for reproduction (figure 4), even slightly increased air and associated water temperatures on the shelf may preclude egg production (figure 6).

Water Volume Effects

Increased air temperature will certainly increase direct loss of water from Devils Hole through evaporation. However, the rate of groundwater flow is almost certainly great enough to render evaporation inconsequential as a determinant of water level in Devils Hole.

An aspect of the dynamics of Devils Hole that has been studied is the flow of groundwater from the east through Devils Hole that is ultimately discharged in Ash Meadows National Wildlife Refuge. As temperatures increase in the Great Basin it is presumed that evapotransportation will initially increase and snow pack will decrease. This will result in a lower amount of groundwater recharge. However, a larger impact to the aquifer that supports Devils Hole will likely come from proposed ground water withdrawals to support an increasing human community in southern Nevada.

Devils Hole was the focus of a landmark U.S. Supreme Court decision (United States v. Cappaert 1976) upholding Federal reserved water rights. As a result the United States District Court for the District of Nevada "…established by a preponderance of evidence that the minimum water level at Devils Hole necessary to preserve the pupfish there is 2.7' [0.82 m] below the copper washer (United States v. Cappaert 1977). The copper washer being a known elevation in Devils Hole.

A deep carbonate aquifer that underlies much of Nevada, western Utah, and a portion of California is the life blood of the wetlands and springs throughout the region including Devils Hole. Eighty percent of the recharge to this aquifer is attributable to 78 basins. Deacon *et al.* (2007) reported that 102 percent of perennial yield of these 78 basins is currently allocated. However, the allocations are divided unevenly among the basins. For example, groundwater rights now exist for 376 percent of the perennial yield in Las Vegas Valley, 331 percent in the Pahrump Valley, and 113 percent in the seven basins that include Ash Meadows. Southern Nevada Water Authority (SNWA) hopes to obtain water rights to an additional 180,800 acre-feet per year of groundwater. Other Nevada communities have pending applications for an additional 870,500 acre-feet of groundwater with the Nevada State Engineer.

Schaefer and Harrill (1995) produced a conceptual model of the effects of the SNWA's proposed withdrawal on the regional groundwater resources. Their model assumed no water withdrawal from the region beyond the 180,800 acre-feet sought by SNWA. Other modelers have followed and with the exception of SNWA's internally produced model, all produced results consistent with those of Schaefer and Harrill which projects groundwater level declines of from 0.3 to 488 m throughout the 78 basins (figure 7). Furthermore they suggest a new steady state may be reached in 100 to 200 years with groundwater level declines of 15 to 152 m predominating in both shallow and deep aquifers. Eventually evapotransportation will decline as water tables drop below the level of phreatophytic root penetration.

Compounding these projections with increased temperatures and decreased precipitation as predicted by Seager *et al.* (2007) may well lower the water level of Devils Hole within the next century. The result of this lower water level has yet to be analyzed but it could well have both biological and legal implications.

Literature Cited

Blinn, D. W. and K. P. Wilson. 2005. Devils Hole Energetics/Community Relationships; Death Valley National Park, California. Final Report to Death Valley National Park. Project No. 7530. 58 pp.

Deacon, J. E. and M. E. Deacon. 1979. Research on Endangered Fishes in the National Parks with Special Emphasis on the Devils Hole Pupfish. Pages 9 -1 19 In, R. Linn (ed.), *Proceedings of the First Conference on Scientific Research in the National Parks*. U.S. National Park Service Transactions and Proceedings, No. 5.

Deacon, J. E., A. E. Williams, C. D. Williams, and J. E. Williams. 2007. Fueling population growth in Las Vegas: How large-scale groundwater withdrawal could burn regional biodiversity. BioScience. 57:688 – 698.

Gustafson, E. A. and J. E. Deacon. 1998. Distribution of larval Devils Hole pupfish *Cyprinodon diabolis* Wales, in relation to dissolved oxygen concentration in Devil's Hole. Final Report to the National Park Service, Death Valley National Park. Contract No. 1443PH813095341. 61 pp.

James, C. D. 1969. Aspects of the Ecology of Devils Hole Pupfish, *Cyprinodon diabolis* Wales. Unpublished Masters thesis, University of Nevada, Las Vegas. 70 pp.

Riggs, A. C. and J. E. Deacon. 2004. Connectivity in desert aquatic ecosystems: The Devils Hole story. In Sada D. W.,

Sharpe S. E. eds. Conference Proceedings. Spring-fed Wetlands: Important Scientific and Cultural Resources of the Intermountain Region, 2002. (11 June 2007; http://www.wetlands.dri.edu/2002RiggsDeacon.pdf.

Seager, R., M. Ting, I. Held, Y. Kushnir, J. Lu, G. Vecchi, H. Hyang, N. Harnik, A. Leetmaa, N. Lau, C. Li, J. Velez, N. Naik. 2007. Model Projections of an Imminent Transition to a More Arid Climate in Southwestern North America. Science. 316:1181 – 1184.

Shrode, J. B. 1975. Developmental temperature tolerance of a Death Valley pupfish (*Cyprinodont nevadensis*). Physiological Zoology, 50: 378-389.

Shrode, J. B. and S. Gerking. 1977. Effects of constant and fluctuating temperature on reproductive performance of a desert pupfish, *Cyprinodonn. nevadensis*. Physiological Zoology, 50: 1 – 10.

United States v. Cappaert. 1976 United States Supreme Court, 426 U.S. 128.

United States v. Cappaert. 1977. United States District Court for the District of Nevada: Unpublished Order, Civil LV_1687 (December 22, 1977).

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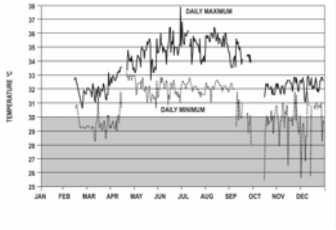

Figure 4. Daily maximum and minimum water temperatures over the inner segment of the shallow shelf at Devils Hole, February to December 2001. From Riggs and Deacon, 2004.

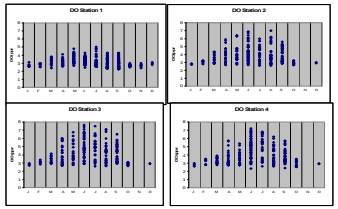

Figure 5. Daily max/min dissolved oxygen for four stations on the shallow shelf in Devils Hole from 6/74 – 9/85. Station 1 is closest to the deep pool, station 2 in mid shelf, and stations 3 and 4 and furthest from the deep pool.

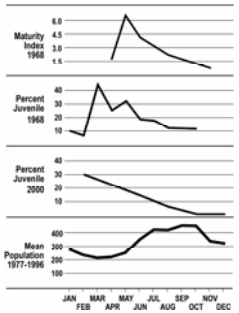

Figure 6. Annual cycles of reproduction and recruitment. From Riggs and Deacon 2004.

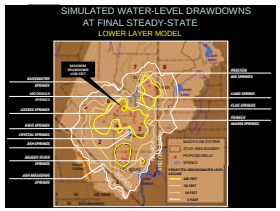

Figure 7. Expected decline in the water table in the deep carbonate aquifer as a consequence of the proposed water withdrawal by SNWA. From Deacon et al, 2007