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**HYDROGEOLOGIC CONTROLS ON THE MOVEMENT OF GROU[illegible]
AT THE NEVADA TEST SITE, NYE COUNTY, NEVADA--
A SUMMARY DESCRIPTION FOR ENVIRONMENTAL RESTORATION**

By Randell J. Laczniak, James C. Cole, David A. Sawyer, and Douglas A. Trudeau

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HYDROGEOLOGIC UNITS

Ground water flowing beneath NTS passes through diverse rocks (fig. 4) that differ substantially in terms of age, composition, and water-bearing properties. These rocks form a complex three-dimensional framework of ground-water conduits and barriers that can be described as hydrogeologic units (aquifers and confining units) on the basis of their ability to store and transmit water (table 1; *near here*). This framework differs significantly from a simple layer-cake model, due to the combined result of four main influences: 1) the initial geometric shape of the rock units ranges from tabular to lenticular to cylindrical; 2) structural and erosional modifications have profoundly changed the thickness and lateral continuity of most major rock units; 3) hydrothermal alteration, contact metamorphism, diagenesis, and thermal-mechanical effects of underground testing have modified rock-hydraulic properties to varying degrees; and 4) tectonic fracturing has altered permeability along fault zones.

Knowledge of this three-dimensional framework has significant gaps, but regional studies provide the basis for predicting the locations of major hydrogeologic units that convey most of the ground water within the upper 5,000 to 7,000 feet of the Earth's crust. These units, first enumerated by Winograd and Thordarson (1975), are revised here and designated: 1) the basement confining unit; 2) the lower carbonate aquifer; 3) the Eleana confining unit; 4) the upper carbonate aquifer; 5) the volcanic aquifers and confining units; and 6) the valley-fill aquifer (table 2; *near here*). Although each of these regional units has internal complexities and although different parts of the NTS region are strongly influenced by different combinations of units, these major subdivisions are useful descriptive elements of the overall conceptual framework.

The rocks that make up these hydrogeologic units include parts of a very thick sequence (more than 35,000 feet) of Paleozoic and older sedimentary rocks (about 280 to more than 600 million years old), local intrusive bodies of Cretaceous granite (about 100 million years old), a thick and extremely variable assemblage of Miocene volcanic rocks (about 8 to 16 million years old), and locally thick deposits of post-volcanic gravel and sand that fill the present-day valleys (Frizzell and Shulters, 1990). Major structural events have also left their imprint on the rocks of the area. This region of the western United States was a stable continental margin until late Devonian time (about 370 Ma) when uplift west and north of the NTS resulted in the erosion and deposition of thick Mississippian sandstones in an active foreland basin (Poole, 1974; Poole and Sandberg, 1991). Compressional deformation during the Sevier orogeny (about 150 to 100 Ma) produced regional thrusts, folds, and (probable) wrench faults that fundamentally rearranged the positions of Paleozoic and older sedimentary rocks, both in terms of depth and in geographic distribution (Armstrong, 1968). Minor granite bodies were intruded in the region during Cretaceous time (100 Ma).

Following erosion throughout most of the early Tertiary Period (65 to 30? Ma), the area in and around the NTS began to be pulled apart along low-angle normal faults and strike-slip faults associated with the formative stages of the modern-day Basin and

GROUND-WATER FLOW AND SUBBASINS

Regional interpretations of ground-water flow within the NTS region are based on the concept of ground-water subbasins. A ground-water subbasin defines the area that contributes water to a major surface discharge. Subbasins are delineated primarily on the basis of: (1) the location of major discharge areas (springs and wet playas), (2) the location of recharge areas (zones of substantial precipitation), (3) exposures of rocks with low water-transmitting potential (low permeability), (4) regional hydraulic gradients determined from measurements of water level, and (5) comparisons of the chemical and isotopic composition of water. Ground-water levels in the vicinity of the NTS range in altitude from about 6,500 feet in the Kawich Range to below sea level at flow models have simulated rates that range between about 23 (Czarnecki and Waddell, 1984) and 3,000 acre-ft/yr (Burbey and Prudic, 1991). The probable conduit for outflow is through carbonate rocks in direct contact at depth (plate 1). Outflow is supported by geochemical data that indicate a similar isotopic and chemical composition for water sampled from the carbonate aquifer in central Amargosa Desert and at springs near Death Valley and Ash Meadows (Winograd and Thordarson, 1975; Winograd and Friedman, 1972).

The Oasis Valley subbasin is the smallest and most western of the three subbasins (plate 1). The subbasin measures 550 square miles and extends north from

Oasis Valley to include the western part of Gold Flat, Black Mountain, and parts of western and central Pahute Mesa. The subbasin adjoins the Alkali-Flat Furnace Creek Ranch subbasin on the east and traverses the western part of the Pahute Mesa underground test area (fig. 3). Volcanic rocks are the dominant hydrogeologic units within the subbasin, although some alluvium is saturated in Gold Flat and Oasis Valley. Granitic and clastic rocks that may underlie the volcanic aquifers and confining units at depth form the hydrologic basement.

Ground water discharges from the Oasis Valley subbasin as spring flow and evapotranspiration, primarily along the Amargosa River from Oasis Valley south to Beatty, Nev. Discharge has been estimated at 2,400 acre-ft/yr (Malmberg and Eakin, 1962). Springs exist as close as 17 miles downgradient from underground testing on Pahute Mesa. The basin is the primary water supply for ranches located in upper Oasis Valley and the residents of Springdale, Nev. Ground water from the subbasin also is used by some residents of Beatty, Nev. for domestic purposes.

Precipitation recharges the subbasin primarily along its northern boundary at the Cactus Range. Recharge from within the subbasin may occur at Black Mountain and Quartz Mountain and Pahute Mesa. Water also enters the subbasin from the north beneath Cactus flat as subsurface inflow. Hydraulic gradients based on regional water-level data indicate that ground water flows primarily south-southwest through western Gold Flat and central Pahute Mesa and on into Oasis Valley (plate 1). At Oasis Valley, water moving southward is diverted up to the surface by the basement confining unit. Rocks that make up the basement confining unit are exposed nearby in the Bull Frog Hills and in the northern part of Bare Mountain.

The boundaries of the Oasis Valley subbasin are not well defined. As shown in plate 1, the northern part of the eastern boundary coincides approximately with a limited flow barrier suggested by Blankennagel and Weir (1973). Other interpretations regard this barrier as a local feature, and extent the eastern boundary to the Kawich Range, thus including more of Pahute Mesa, Timber Mountain, and Gold Flat within the subbasin (Burbey and Prudic, 1991; White and Chuma, 1987; Borg and others, 1976;

Outflow from beneath Oasis Valley into the Alkali Flat-Furnace Creek Ranch subbasin is supported in the literature, but few quantitative estimates are given. Malmberg and Eakin (1962) estimate ground-water outflow at 400 acre-ft/yr through a narrow veneer of valley fill that overlies the basement confining unit along the Amargosa River south of Beatty, Nev. Another outlet may be through the low-permeability rocks that make up the basement confining unit.

The Alkali Flat-Furnace Creek Ranch subbasin lies between and is tributary to the Ash Meadows and Oasis Valley subbasins (plate 1). The subbasin is about 2,800 square miles and traverses much of the western half of the NTS to includes parts of the Rainier Mesa, Pahute Mesa, and the Shoshone Mountain underground test areas (fig. 3). The subbasin is bounded on the north by hydrologic divides associated with recharge areas, on the east by a recharge divide and the Eleana confining unit, and on the west by subsurface structures which probably coincide with caldera-boundary faults. The principle aquifers in the northern part of the subbasin are volcanic aquifers, where as valley-fill and carbonate aquifers dominate in the southern part. Volcanic rocks in the northern part of the subbasin are underlain by Paleozoic clastic and carbonate rocks on the east and granitic rocks on the west.

Ground water discharges from the Alkali Flat-Furnace Creek Ranch subbasin primarily as evaporation from Alkali Flat and as spring flow and evapotranspiration near Furnace Creek Ranch in Death Valley. The subbasin provides about 50 percent of the NTS water supply (D.B. Wood, U.S. Geological Survey, written commun., 1991). Downgradient of the NTS, the subbasin supplies water to the rural communities of Amargosa Valley, Nev. and Death Valley Junction, Calif., to a few ranches, farms, and mining operations within the Amargosa Desert, and to private recreational establishments and Federal facilities within the Death Valley National Monument, Calif. Spring flow from the subbasin is a major source of water supporting the plant and wildlife within Death Valley. Discharge from the subbasin is difficult to separate from the total discharge occurring throughout all of Death Valley. Waddell and others (1984) estimate annual discharge from the subbasin at about 16,500 acre-ft. Of this total, 10,500 acre-ft/yr discharges at Alkali Flat and the remainder from springs near Furnace Creek Ranch.

Precipitation recharges the subbasin along its northern boundary at the Kawich Range, and Reveille Range and along the northeastern boundary at the Belted Range, Rainier Mesa, and Shoshone Mountain. Recharge occurs from within the subbasin throughout eastern Pahute Mesa and at the southern part of the Kawich Range. Precipitation falling on Timber Mountain and the Funeral Mountains also may contribute some recharge to the subbasin. Infiltration of drainage from Fortymile Canyon during periods of intense surface runoff has been proposed as another potential source of recharge (Claassen, 1985; Czarnecki and Waddell, 1984).