REGIONAL GROUND-WATER FLOW DIRECTIONS AND SPRING RECHARGE AREAS IN AND NEAR THE FORT LEONARD WOOD MILITARY RESERVATION, MISSOURI

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Abstract

Regional ground-water flow at the Fort Leonard Wood Military Reservation (FLWMR) generally is east and west away from a regional ground-water divide towards the Big Piney River and Roubidoux Creek. Ground-water flow in the northern FLWMR is strongly affected by solution-enlarged fractures and bedding planes in the Roubidoux Formation and Gasconade Dolomite. Several large springs located on the FLWMR (Sandstone Spring) and off the FLWMR (Shanghai Spring, Roubidoux Spring, and Miller Spring) receive water from precipitation recharge and stream flow loss on the FLWMR.

Introduction

A basewide regional geologic and hydrologic assessment of the FLWMR, south-central Missouri, was begun in 1994 by the U.S. Geological Survey (USGS) in cooperation with the FLWMR Directorate of Public Works, Environmental Division. The assessment area included the 64,000-acre FLWMR and surrounding areas bounded to the east by the Big Piney River, to the west by Roubidoux Creek, to the north by Interstate 44, and to the south by the southern boundary of the FLWMR (fig. 1). The purpose of the 1-year study was to describe and map geologic structures that can affect ground-water flow and to conduct ground-water-level measurements in area wells and dye-trace investigations to determine regional ground-water flow directions and spring recharge areas in and near the FLWMR.

Geologic Framework

Three rock formations are exposed at the FLWMR. From youngest to oldest, these formations are the Jefferson City Dolomite, Roubidoux Formation, and Gasconade Dolomite. The Jefferson City Dolomite is exposed in the southern part of the FLWMR along a central upland ridge between the Big Piney River and Roubidoux Creek. The underlying Roubidoux Formation is exposed in upland areas and hillsides on the western, eastern, and northern parts of the FLWMR. The lithology of the Roubidoux Formation ranges from a sandstone upper zone to a dolostone lower zone. The underlying Gasconade Dolomite primarily is exposed along the Big Piney River and Roubidoux Creek valleys where it forms prominent bluffs. Beneath the Gasconade Dolomite but not exposed in the study area are the Eminence Dolomite, Potosi Dolomite, Derby-Doe Run Dolomites, Davis Formation, Bonneterre Formation, Lamotte Sandstone, and Precambrian basement rocks.

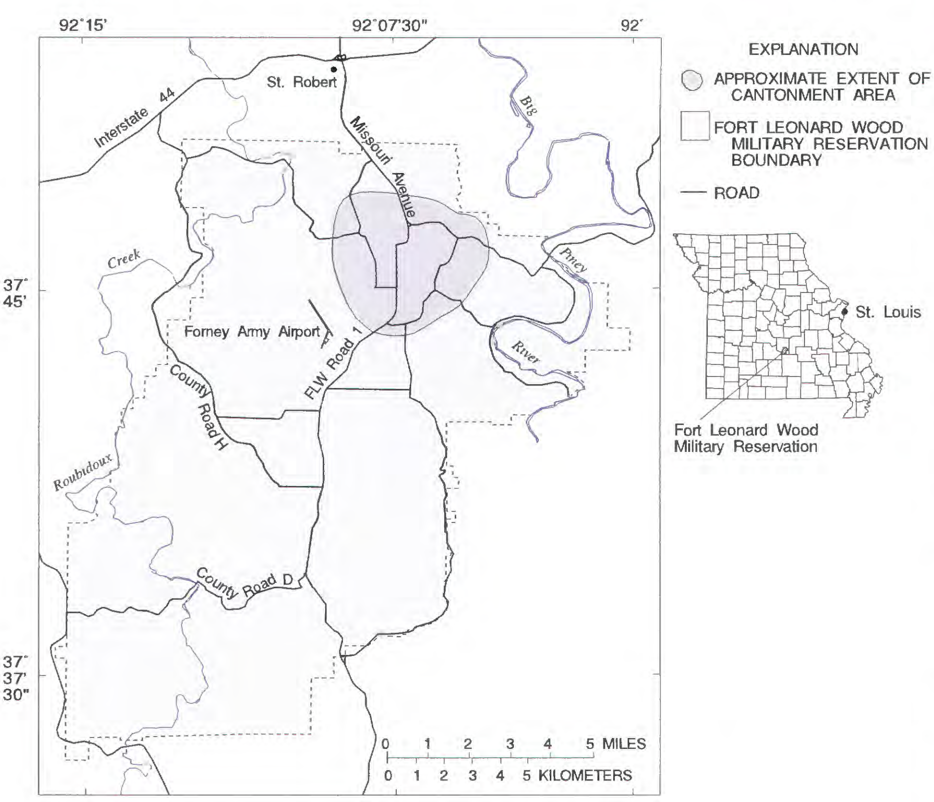

Figure 1. Location of the Fort Leonard Wood Military Reservation.

Ground-Water Movement Controlled by Fractures and Karst Features

The geologic mapping also included a concentrated effort to identify fractures (a break in the bedrock caused by stress relief, including cracks, joints, and faults), bedding planes (a rock layer surface that tends to split, break, or separate from overlying or underlying layers), and other rock features that can affect ground-water flow. Selected physical properties of observed fractures and bedding planes were described. These properties included length, width, and orientation of the rock opening, and evidence that fracture or bedding-plane openings were being reduced (cementation) or enlarged (dissolution) by ground-water flow.

Limestones and dolostones are carbonate rocks capable of being dissolved by ground water, a process called dissolution. Karst is a geologic terrane caused by dissolution of carbonate rock. Karst terrane typically is characterized by the presence of sinkholes, caves, streams that lose water, and springs. These features are common in the central and northeastern part of the FLWMR and can greatly increase the rate of ground-water flow through carbonate rock. No evidence of solution activity was observed in areas where the Jefferson City Dolomite is exposed. Most caves and large springs at the FLWMR are contained in the upper part of the Gasconade Dolomite.

Observations of hundreds of fractures in the study area revealed that about 98 percent of all fractures have openings less than 0.5 inch, and less than 10 percent of the fractures extended through the entire thickness of the formation (through-going) in which they occur. Of all observed fractures, only about 4.5 percent in the Jefferson City Dolomite, about 1.5 percent in the Roubidoux Formation, and about 20 percent in the Gasconade Dolomite showed evidence of solution activity. Bedding planes in the lower carbonate-rich part of the Roubidoux Formation and upper Gasconade Dolomite showed evidence of extensive rock dissolution such as solution cavities and bedding-plane controlled caves. These bedding-plane features and the lack of substantial solution activity in fractures indicate that most ground water is transported from recharge areas to large springs through solution-enlarged bedding planes rather than through fractures.

The magnitude of the bedding-plane solution activity in the lower Roubidoux Formation is apparent from the large structural differences between the top of the Gasconade Dolomite and the Roubidoux Formation. Bedding planes in the upper Gasconade Dolomite are nearly horizontal, but bedding planes in the sandstone beds of the upper part of the overlying Roubidoux Formation consistently show a pattern of narrow steep-sided troughs and ridges. This difference probably is caused by extensive dissolution of the dolomitic lower part of the Roubidoux Formation and subsequent collapse of the overlying sandstone-rich beds.

Many of the sinkholes in the north-central part of the FLWMR are located along a 1-mile-wide linear trend oriented northeast to southwest (fig. 2). The axis of

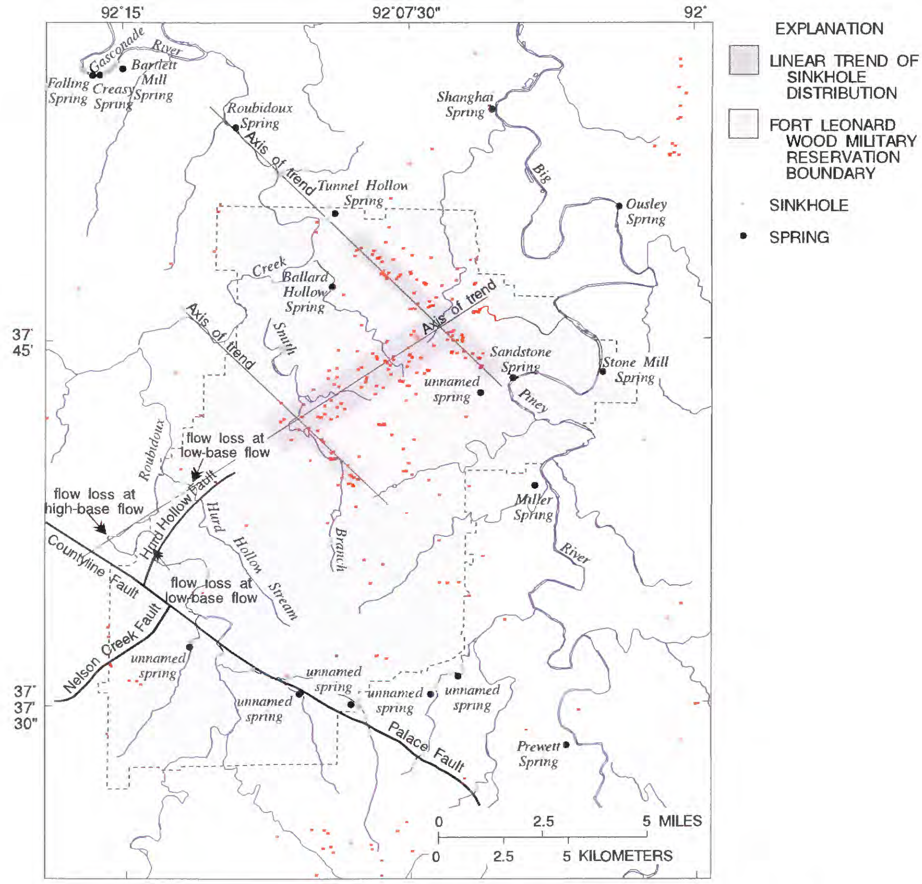

Figure 2. Distribution of sinkholes and springs in and near the Fort Leonard Wood Military Reservation.

this band of sinkholes is parallel to a 1.5-mile-long near linear reach of Roubidoux Creek. This reach of the creek is within a longer reach of Roubidoux Creek that is characterized by a sequence of near right-angle shifts in the stream channel and complete flow loss. The axis intersects Hurd Hollow Stream at the point of flow loss in that creek. The occurrence of abrupt changes in stream channel directions, linear stream segments, flow loss in two streams, and a linear band of sinkholes oriented along a common axis strongly indicates an area of substantial hydrologic control by fractures. Two narrower bands of sinkholes are oriented northwest to southeast. The axes of these bands coincide with near linear reaches of Roubidoux Creek in an area characterized by abrupt stream-channel changes.

Ground-Water Yield to Wells and Flow Patterns

The rock sequence from the Roubidoux Formation to the Potosi Dolomite, part of the thick Ozark aquifer, are productive water-bearing formations at FLWMR. The uppermost Jefferson City Dolomite normally is unsaturated; however, locally it can be partly saturated. Wells completed in the Roubidoux Formation-Gasconade Dolomite rock sequence commonly yield several tens to several hundreds of gallons of water per minute. Wells completed in the Potosi Dolomite can yield from several hundreds to as much as 1,000 gallons per minute.

Recharge to the Ozark aquifer primarily is by percolation of precipitation through overburden and bedrock. Ground-water flow in non-karst areas is controlled by regional topography. General ground-water-flow directions were determined by mapping and contouring water-level altitude measurements made in domestic, public-supply, and monitoring wells. Ground-water flow directions typically are perpendicular and downgradient to the contours. However, a complex combination of flow through solution-enlarged bedding planes causes local anomalies in flow directions at the FLWMR. Water-level measurements were made twice during the study, once during seasonal high-base flow and once during seasonal low-base flow conditions.

Ground-Water Levels—High-Base Flow

Sixty high-base flow water levels were measured from November 2 to December 2, 1994. Ground-water levels in the southern one-half of the mapped area were higher along the major ridges and lower in the major river valleys (fig. 3). Ground water flows from the higher altitudes of the upland ridges (recharge areas) downgradient to the lower altitude regional streams (discharge areas). Regional ground-water levels generally are 100 to 200 feet beneath the smaller upland streams. The regional ground-water divide between the Big Piney River and Roubidoux Creek is offset slightly to the west of the regional topographic divide, indicating that bedrock is more permeable east of the topographic divide.

In the central part of FLWMR, the regional ground-water divide between the Big Piney River and Roubidoux Creek is as much as 2 miles west of the regional topographic divide (fig. 3). This large lateral separation between the ground-water and topographic divides indicates a much larger bedrock permeability east of the topographic divide. Much of the ground-water flow east of the ground-water divide is northward toward Shanghai Spring rather than directly eastward to Big Piney River. This northward redirection of ground-water flow is caused by the well-developed karst terrane as evidenced by the large concentration of sinkholes in the central and northeastern parts of the FLWMR.

Ground-Water Levels—Low-Base Flow

Low-base flow water-level measurements were made from August 28 to August 31, 1995, in the same general set of wells as the high-base flow measurements. Low-base flow ground-water levels were similar to the high-base flow measurements with the notable difference that low-base flow water levels were about 35 feet lower within and near the northern part of the FLWMR and about 10 feet lower in the Roubidoux Creek valley.

Vertical Ground-Water Flow

Based on water-level measurements made in three well pairs located on the FLWMR, vertical hydraulic gradients generally are thought to be small (probably less than about 10 feet per 100 foot decline in altitude) and downward from the Gasconade Dolomite to the Potosi Dolomite. Where rock dissolution is substantial in the Roubidoux Formation and Gasconade Dolomite, water is rapidly transported through conduits to discharge points (springs) several hundred feet lower than the upland recharge area. Vertical hydraulic gradients may be upward from the Potosi Dolomite in these areas because hydraulic heads in the Roubidoux Formation and Gasconade Dolomite are substantially lowered by rapid ground-water transport to discharge points.

Dye-Trace Investigations of Fracture and Conduit Flow

Dye-tracing techniques were used at the FLWMR to supplement water-level measurements and provide evidence of hydraulic connections between ground-water recharge areas, such as sinkholes and losing streams, and ground-water discharge areas, such as springs, seeps, and perennial streams. Dye-tracing investigations are a valuable method for determining ground-water flow rates and directions in complex karst terrane and for defining spring recharge areas.

Ten dye-trace tests with successful recovery of dye were conducted by the USGS at the FLWMR during the study. Several historical dye-trace tests also have been conducted at the FLWMR. Dye injection locations were dictated by the availability of large openings through the overburden to the water table. These include openings in the bottom of sinkholes, stream reaches where substantial flow is lost to the subsurface over a short

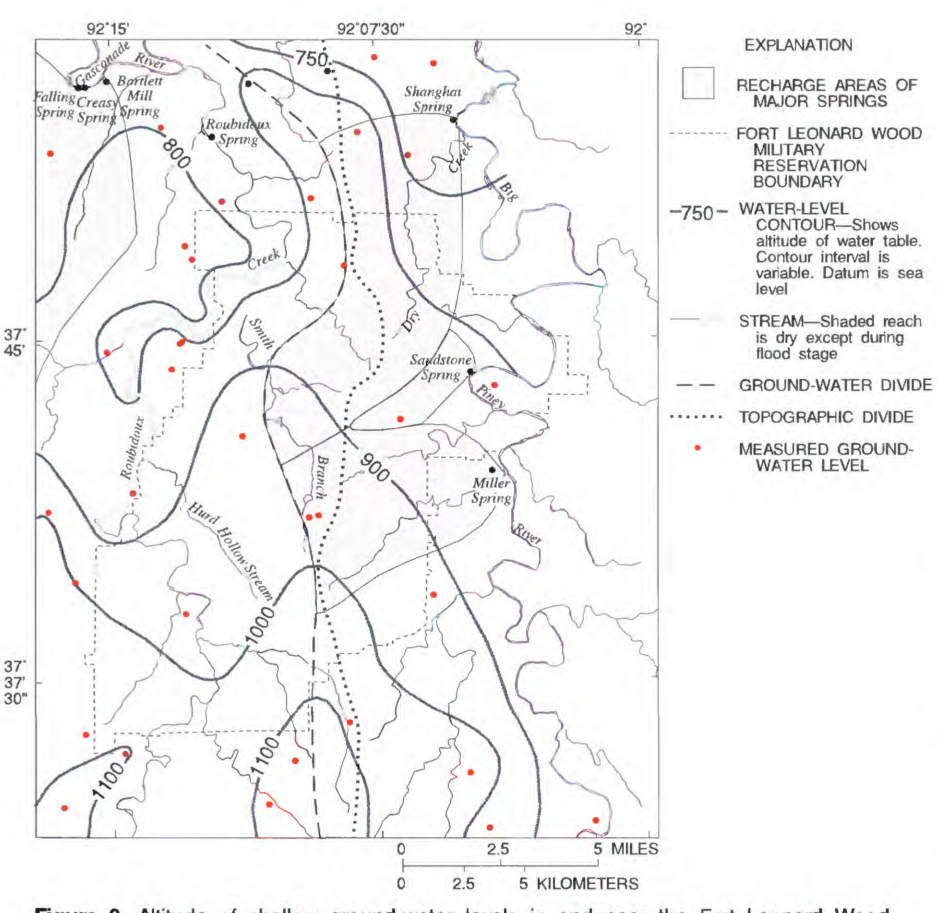

Figure 3. Altitude of shallow ground-water levels in and near the Fort Leonard Wood Military Reservation during high-base flow conditions (November 2–December 2, 1994).

distance, and an abandoned monitoring well.

The dye-tracing procedure included placing a fluorescent dye (fluorescein, Rhodamine WT, or eosine) in the injection opening and, when necessary and practical, injecting several hundreds of gallons of water into the injection opening to flush the dye into the subsurface. Activated charcoal packets were placed in water at potential recovery sites to adsorb dissolved dye. Adsorbed dye was removed from the charcoal by soaking the packets in a chemical solution. The solution was then analyzed by a scanning spectrofluorophotometer for the presence of dye.

Spring Recharge Areas

The probable recharge areas of four springs on and near the FLWMR were determined using dye-trace data and ground-water-level measurements (figs. 3, 4). The combined recharge areas of Falling, Creasy, and Bartlett Mill Springs northwest of the FLWMR are based on dye-tracing investigations conducted by the Missouri Department of Natural Resources, Division of Geology and Land Survey (on file at the office in Rolla, Missouri). Spring recharge area boundaries at the FLWMR were estimated using injection points of successful dye-traces, and ground-water flow lines and divides determined from water-level maps. The probable recharge area of Shanghai Spring lies west and southwest of the spring and encompasses most of the cantonment area of the FLWMR. The western recharge boundary is the regional ground-water divide. The probable recharge area for Sandstone Spring extends west of the spring and shares common boundaries with the recharge areas of Shanghai Spring and Miller Spring. The probable recharge area of Miller Spring extends west of the spring to the regional ground-water divide and is assumed to share a common boundary with Shanghai Spring and Sandstone Spring [referred to as the pumping station spring in Imes and others (1996)]. No recharge area has been defined for Roubidoux Spring. However, dye-trace tests and spring discharge measurements show that Roubidoux Spring receives surface runoff from upstream of injection points shown in figure 4 on Roubidoux Creek and Hurd Hollow Stream. Discharge measurements at Roubidoux Spring indicate that about one-third of the spring flow cannot be attributed to surface water lost from Roubidoux Creek.

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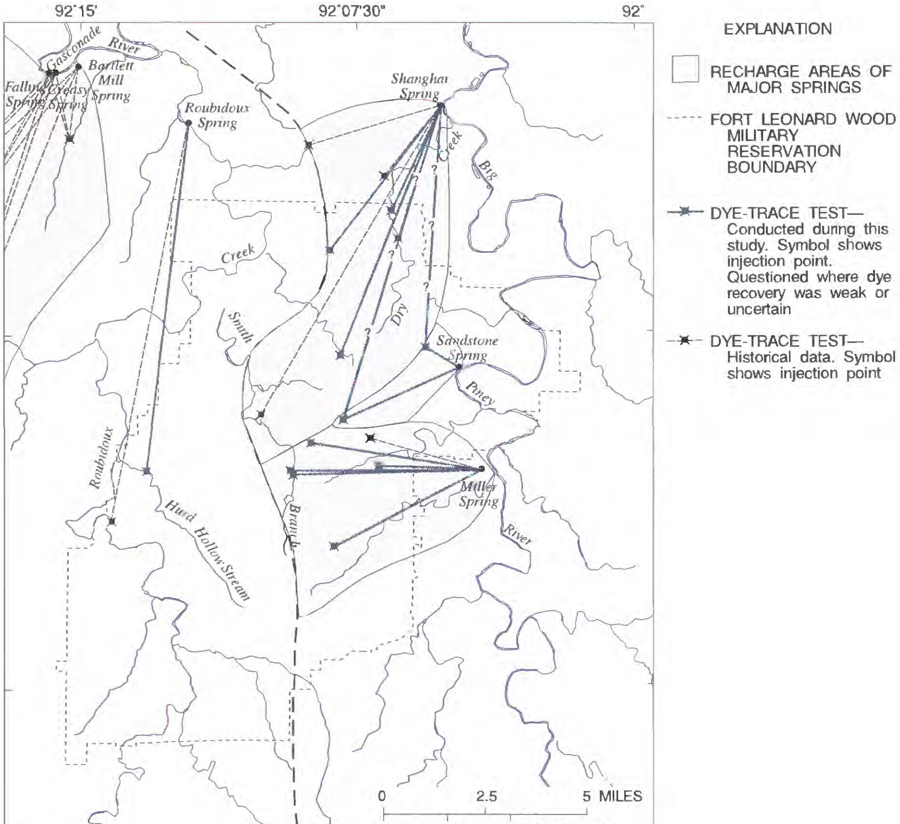

Figure 4. Injection and recovery points for dye-trace tests in and near Fort Leonard Wood Military Reservation.

References

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