Subsurface Geologic Investigation of Fountain Hills and the Lower Verde River Valley, Maricopa County, Arizona

by

Steven J. Skotnicki*, Erin M. Young**, Tomas C. Goode**, and Greg L. Bushner***

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416 W. Congress St., #100, Tucson, AZ 85701

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*formerly with Arizona Geological Survey
416 W. Congress, Suite #100, Tucson, Arizona 85701

**HydroSystems, Inc
1220 S. Park Ln., Suite 5, Tempe, Arizona 85281

***URS Corporation
7720 N. 16th Street, Suite 100, Phoenix, Arizona 85020

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INTRODUCTION

The Lower Verde River Valley is a discrete groundwater basin separated from the Phoenix basin by the McDowell Mountains and bounded on all sides by bedrock, (see figure 1). The basin formed during the late Miocene to Pliocene in response to crustal extension during the Basin and Range orogeny. The perennial Verde River flows southward across the valley from Bartlett Dam in the north to its confluence with the Salt River on the east side of Mount McDowell in the south. Two major ephemeral streams join the Verde River within the valley. Camp Creek drains the northwest part of the basin near Humbolt Mesa and enters the Verde River at Needle Rock. Sycamore Creek drains the northeast part of the basin, on the west side of the Mazatzal Mountains, and enters the Verde just north of Fort McDowell. Both streams typically show no surface flow except during periods of extended and heavy rainfall.

The purpose of this study is to try to delineate the subsurface geology beneath the Town of Fountain Hills and the Lower Verde River Valley in order to place constraints on the shape and distribution of the groundwater reservoir(s). The surface geology was compiled mostly from recent geologic mapping by workers at the Arizona Geological Survey (see previous work section below) and by students from Arizona State University. The subsurface geology was interpreted from examination of over two hundred well logs obtained from the Arizona Department of Water Resources, combined with structural interpretations based on observed surface geology and geophysical data.

The U.S. Army established Fort McDowell on September 7, 1865 to protect settlers against Apache Indian attacks (McDonald and Padgett, 1945). After 15 years the fort was abandoned in 1890 and established as an Indian reservation in 1891. The Fort McDowell Indian reservation is a strip of land about four miles wide and ten miles long centered on the Verde River that occupies the south-central part of the valley. East of the reservation is the Tonto National Forest. To the south is the Salt River Pima/Maricopa Indian Community. To the west is the Town of Fountain Hills and a mix of State, federal, and private land. The developments of Tonto Verde and Rio Verde have sprung up within the last ten years on the north side of the Fort McDowell Indian Reservation.

Fountain Hills Blvd. provides good north-south access to the center of the valley and connects with the east-west Rio Verde Road on the north side of the valley. Rio
Figure 1. Index map showing the geography and structure in the Lower Verde River valley.

\[ = \text{strike and dip direction of Middle and Late Tertiary sedimentary and volcanic rocks.} \\
\times = \text{faults, ball on down-thrown side} \\
\boxed{} = \text{pre-Late Tertiary bedrock}
Valley Road turns into Dynamite Road on the west side of the divide near Pinnacle Peak. State Route 87 slices east-west across the southern and eastern parts of the basin. The development of Goldfield Heights sits on the east side of the Verde River, southeast of Adams Mesa and north of State Route 87. The area between State Route 87 and Bartlett Dam is the least accessible area in the Lower Verde River valley and can generally only be accessed from dirt roads on the east side of Adams Mesa and the graded road to Sugarloaf Mountain.

**PREVIOUS WORK**


McDonald and Padgett (1945) were the first to study the hydrology of the basin in detail. They described the history of water usage in the area and the general geology. Thomsen and Schumann (1968) studied the water resources of the Sycamore Creek watershed and also described the general geology. Kokalis (1971) and Pope (1974) made detailed studies of the Salt and Verde River terraces, respectfully, and interpreted the provenance of the river cobbles. Pewe (1978, 1987) described terraces along the lower Salt and Verde Rivers, noting their height above the river, the degree of calcium carbonate cementation, and their downstream-converging longitudinal profiles. Morrison (1985) provided brief descriptions of these terraces and correlated them to other terrace sequences in central Arizona. Camp (1986) produced a series of soil maps, which includes the Lower Verde River valley. Cooley (1973) produced a map showing the
distribution and estimated thickness of alluvial deposits in the Phoenix area, including the Lower Verde River valley.

Deslauriers (1977) made a detailed gravity and magnetic survey in the Lower Verde River Valley. His work was later incorporated into state-wide gravity maps produced by Lysonski et al., (1981). Harris (1997) measured the uranium distribution in the Cave Creek-Carefree area.

There are several investigators that researched the hydrology specific to the Town of Fountain Hills. Manera & Associates (1974) collected aquifer test data on wells in this area. These data were reviewed by Nemecek and Briggs (1975) to further refine the aquifer test data results in support of an Assured Water Supply for the Town. There are many others authors that conducted work specific to the Town of Fountain Hills including Turner (1968) who provided preliminary research regarding the water resources of the area and DCI, Inc. (1995) who supplied a hydrologic report in support of an Assured Water Supply. Manera & Associates (1973, 1974, and 1975a) wrote reports on the geology and hydrology of the Fountain Hills area. Halpenny (1975) provided an analysis of the evaporative losses from the lake and the fountain in Fountain Lake. There were several geophysical analysis conducted and reported by Ward (1975), Group Seven (1976), and Harshbarger and Associates (1975). Manera & Associates (1975b) published a review of the aforementioned reports. Most recently HydroSystems, Inc. (HSI has written several reports including a report on the hydrogeology of the Town of Fountain Hills (1998), a report developed for the aquifer storage and recovery (ASR) project that is currently in operation, HSI (1999), and several reports that area currently pending including a Monitor Well Completion Report (HSI, 2001), an ASR Well Completion Report (HSI, 2002a), a Test Well Report (HSI, 2002b), and the Numerical Groundwater Flow Model of the Fountain Hills Sub Basin (HSI, 2002c).

PRE-BASIN GEOLOGY

Proterozoic basement

The pre-basin rocks exposed in the Lower Verde River are dominated by Proterozoic igneous and metamorphic rocks unconformably overlain by Middle Tertiary
sedi mentality and volcanic rocks. Early Proterozoic volcanic and sedimentary rocks were buried and metamorphosed around 1.7 Ga (Ga=billion years before present). These rocks are exposed today in the southern McDowell Mountains, north of Carefree, north and northeast of Bartlett Lake, and at Herder Mountain southeast of Bartlett Lake. Previous workers have correlated these rocks with several different Early Proterozoic rock sequences in the state (for a good overview see Anderson, 1989). The rocks are composed mostly of slate, phyllite, schist, quartzite, greenstone, and metavolcanic rocks. Except near contacts with granite intrusions these rocks rarely exceed lower to middle greenschist metamorphic facies.

The Early Proterozoic supracrustal rocks were later intruded by coarse-grained calc-alkaline granites between ~1.69 and 1.65 Ga. Several of these older plutons surround the study area. The Verde River Granite (not dated) intrudes the area directly north and northwest of the Valley. To the northeast, the Sunflower Granite holds up the central part of the Mazatzal Mountains and has been dated at ~1.69 Ga (Silver, 1969). South of the Sunflower Granite, the large mass of the southern Mazatzal Mountains is composed mostly of a coarse-grained granite tentatively called the Beeline granite (Skotnicki, unpublished report). Isachsen et al., (1999) reported a U-Pb date of ~1632 Ma (Ma=million years before present) for this rock. To the south the Usery Mountains Granite borders the southern end of the basin. All of these older granites are at least partially weakly to strongly foliated as a result of deep-seated compression and shearing that occurred during and after emplacement.

These older rocks were intruded by younger coarse-grained, alkaline granites at ~1.4 Ga. One of the largest of these plutons in the state is centered over the northern portion of the Lower Verde River valley. Tentatively called the Carefree Granite (Skotnicki, unpublished report), it is characterized by large light gray to pink K-feldspar phenocrysts between 1 and 4 cm long. Except for a relatively narrow northeast-striking shear zone, this granite is much less deformed than the older granites. It weathers and erodes relatively easily and has formed a broad low-relief pediment surrounding the northern end of the basin. This granite has supplied much of the detritus that has been incorporated into the Tertiary and Quaternary sedimentary deposits that fill the valley.
**Middle Tertiary Rocks**

All younger Proterozoic, Paleozoic, and Mesozoic strata in this area are missing. The Proterozoic basement was uplifted, eroded, and beveled relatively flat probably several times since it was first exposed at the surface sometime after ~1.3 Ga. Tan- to red-colored granite-rich conglomerates (often referred to as the “Whitetail Conglomerate” in other parts of the state) were deposited directly on the Proterozoic bedrock beginning possibly as early as the Late Oligocene or Early Miocene. Unpublished Ar/Ar ages from the Superstition volcanic field (Ferguson et al., in press) located to the southeast of the study area indicate Whitetail sedimentation predates ~18.5 Ma.

During the Late Oligocene and Early Miocene (27.3 to 18.9 Ma; Leighty, 1998) scattered intermediate to moderately felsic volcanic flows erupted at the surface. Rhyolite dikes and small rhyolite domes crop out in two places in the basin; west of Camp Creek in the Wildcat Hill 7.5’ quadrangle and southeast of Granite Mountain in the Maverick Mountain 7.5’ quadrangle. These outcrops have not been dated.

In the southern part of the Lower Verde River Valley pre-volcanic red-beds are intruded and interbedded with mafic volcanic flows dated at ~18.7 Ma (Shafiqullah et al., 1980). These red beds are composed of interbedded sandstone and coarse bouldery debris flows containing clasts of granite and minor amounts of metamorphic rocks.

Voluminous and widespread basaltic flows interbedded with the upper parts of the conglomerate near Bartlett Dam and north of Stewart Mountain have been dated at about 15 Ma (Shafiqullah et al., 1980). These basalt flows are correlated with similar interbedded sedimentary and basaltic rocks widespread in central Arizona referred to as the Hickey Formation (Anderson and Creasey, 1958; Scarborough, 1979; Eberly and Stanley, 1978). Eruption of the Hickey volcanics lasted between 16.2 and 9.2 Ma (Leighty, 1998).

**Late Tertiary Deposits**

The Middle Tertiary volcanic and sedimentary rocks were faulted and tilted into a series of west-dipping tilted-blocks during the Basin-and Range disturbance. The Basin-and Range disturbance involved high-angle block faulting that created elongate mountain
ranges and intervening basins. As Leighty (1998) pointed out, “this event, dated at between 13 and 8 Ma, has been traditionally cited as the main cause of the present physiography of the present Basin-and-Range in southern and western Arizona,” (Eberly and Stanley, 1978; Shafiqullah, 1980). It was during this time that the Lower Verde River basin formed.

Basalt-rich conglomerates of the Needle Rock Formation (map unit Tsn), exposed a few miles south of Bartlett Dam, are the oldest exposed basin-fill deposits in the area. This rock contains almost solely angular to subrounded pebbles to small boulders of basalt in a tan silty to sandy matrix. It is moderately to strongly consolidated and cemented with abundant coarse calcite spar. Close to the contact with the underlying basalt, beds dip as much as $10^\circ$ to the southwest. Over a distance of less than a mile southward the dip decreases until the beds appear nearly flat-lying. This gradational change in dip indicates that the lower part of the Needle Rock Formation was deposited and tilted during faulting, while the upper part was deposited after most of the faulting had ceased.

Coarse conglomerates of the Needle Rock Formation grade rapidly into coarse sandstones immediately southwest of Needle Rock. Over a lateral distance of a few hundred feet these sandstones grade abruptly into fine-grained sandstone and siltstone of the Pemberton Ranch Formation (map unit Tsp, informal name). The Pemberton Ranch Formation is exposed in the valley only locally beneath capping remnants of younger more resistant rocks. However, drill-logs indicate the unit is widespread throughout the central part of the basin. The Pemberton Ranch Formation is composed of interbedded, thinly bedded fine-grained sandstone, siltstone, claystone, and minor coarse sandstone and conglomerate layers. Narrow, cylindrical carbonate and clay concretions several millimeters in diameter may represent root tubes (Pope, 1974) or burrows. This unit probably represents the deposits of a former playa, and shows that the basin at this time still possessed internal drainage.

Coarse, cobble-rich conglomerates (map unit Tsm) overlie the playa deposits. They contain abundant basalt clasts and clasts derived from Proterozoic rocks exposed outside the basin, in a sandy to grussy matrix. The coarse, well rounded, extra-basinal river cobbles are strong evidence that the basin had attained external drainage at this
time. The catalyst for inception of external drainage is uncertain. It likely involved incision or headward erosion across some bedrock dam at the south end of the basin.

It is clear that deposits continued to fill the basin even after external drainage was established. Younger basin-fill deposits (map unit Tsy) appear to unconformably overlie map unit Tsm on the north side of Fountain Lake and farther north. Although map unit Tsm may represent axial river deposits contemporaneous with map unit Tsy, the significant relief between the two units exposed on the north side of Fountain Lake argues against this idea. It is the younger basin-fill deposits (map unit Tsy) that underlie the Town of Fountain Hills and indeed much of the Lower Verde River Valley. Although these deposits do not exist in the northwest part of the basin they probably at one time existed there and have since been stripped away by erosion.

BASIN STRUCTURE

Faults

Several fault systems exposed in the bedrock surrounding the basin all show similar curved geometries, concave to the northeast (see figure 1). The Sugarloaf Fault on the east side of the basin is a down-to-the-east normal fault down-dropping basalt and conglomerate against granite. Differential thickness of units on opposite sides of the fault show that faulting initiated during deposition of the Miocene conglomerate and continued on into the Quaternary (Skotnicki and Leighty, 1998; Peartree et al., 1995).

The Horseshoe Dam Fault has the same geometry as the Sugarloaf Fault and cuts even older volcanic and sedimentary rocks of the Chalk Canyon Formation. This fault has also been active as recently as Late Pleistocene (Piety and Anderson, 1991). The Horseshoe Fault is well defined in the Horseshoe Basin but where it curves to the southeast, near Bartlett Lake, it is defined by a series of parallel, curving, and possibly discontinuous fault strands. These parallel fault strands cut through granite that slopes northeastward toward the Verde River. A well-formed, south-sloping pediment is beheaded by the crest of the northeast-facing slope, suggesting beheading may have been related to rapid erosion caused by relatively recent movement along the parallel fault strands.
These southeast-striking fault strands are difficult to follow across Bartlett Lake through the granite. At least one large fault down-drops mid-Tertiary volcanic and sedimentary rocks on the north against granite on the south. Several other faults slice southeastward across the Maverick Mountain quadrangle. Where visible, they appear to merge with or curve southward into more north-south-striking faults.

The southern part of the Carefree Fault system exposed in the northwest part of the basin also has the same scalloped, concave-to-the-east geometry. To the north the fault curves northwestward. Unlike the other faults just described, this fault system is down-to-the-southwest and forms the northern boundary of the Late Tertiary Carefree Basin (Leighty et al., 1997). The structure of the Carefree Basin itself is complex and probably includes older, inactive north-dipping normal faults subsequently cut by the Carefree Fault. The Carefree Fault has also been active in the Quaternary and cuts sediments at least as young as middle Pleistocene (Pearthree and Scarborough, 1984; Skotnicki et al., 1997).

Another fault, here informally called the Camp Creek Fault, strikes N-NW along the west side of Camp Creek, west of Blue Mountain. It has a down-to-the-east sense and down-drops late Tertiary basin-fill sediments (map unit Tsy) against granite. Basin-fill sediments covering the fault locally show no displacement, indicating that faulting ceased before the basin had completely filled with sediment. Although poorly exposed, this fault is important for interpreting the structure beneath the basin to the south. The McDowell Mountains form a resistant bedrock spine that curves southeastward where it meets the confluence of the Verde and Salt Rivers. As described, many of the other faults in the region have the same scalloped southeast-curving, down-to-the-east geometry. It is possible that the Camp Creek Fault also curves to the southeast under the Lower Verde River Valley. The southwest dips of the mid-Tertiary basalts on the east side of the basin were formed by moderately east-dipping normal faults. The absence of Tertiary rocks in the McDowell Mountains, except in the south, suggests they were at higher structural levels as a result of uplift, and have subsequently been eroded away. If so, this indicates a minimum of about 3,000 feet of vertical displacement of the mid-Tertiary rocks between the top of the present McDowell Mountains and the estimated top of basalts now buried beneath the Lower Verde River Valley. The Camp Creek Fault may be the master fault of
a half-graben separating the now-buried mid-Tertiary rocks in the basin on the east from
the uplifted Proterozoic rocks on the west.

Gravity Data

Gravity maps are a compilation of individual measurements taken at separate
ground stations. These measurements must be corrected for differences in elevation and
for slope effects—nearby mountains will cause the measuring device to swing slightly in
the direction of the larger mass and affect the vertical component of the gravity
measurement. With those corrections, the gravity measurements are then most affected
by differences in the density of the underlying material. More porous sedimentary rock
will be less dense and have less corresponding gravity than denser, less porous igneous
and metamorphic rock. The resulting data hopefully shows the largest gravity lows where
sedimentary rocks are the thickest—logically in the center of depositional basins.
However, a similarly high gravity measurement in any particular spot can be obtained
from either a small, dense mass near the surface, or a larger, less dense mass farther
down. There are many subsurface mass configurations that show similar gravity effects.
There is no unique solution. Therefore, gravity contour maps should be viewed as models
rather than as accurate representations of the subsurface geology.

Both the complete Bouguer anomaly map and the residual gravity map produced
by Deslauriers (1977) show a north-northwest-trending gravity low in the north-central
part of the basin. The maps show that the strongest gravity low is about 3-4 miles N-NW
of the Asher Hills. This corresponds relatively well to the gravity map produced by
Lyonski et al., (1981) which places the gravity low slightly farther to the northwest (see
figure 2). The most logical conclusion from these data is that the greatest gravity low
corresponds to the deepest part of the basin. If movement along the Camp Creek Fault
really did create a half-graben, one might expect the deepest part of the basin to be close
to the western side of the basin. Projecting the Camp Creek Fault south-southwestward,
the gravity low sits between 1-2 miles east of the inferred fault trace. This is consistent
with the existence of the Camp Creek Fault at depth. Notice that the gravity contours are
steepest in the same area where the Camp Creek Fault projects south-southeastward. This
corresponds to the greatest decrease in density (west to east) anywhere in the basin and is
Figure 2. Complete residual Bouguer gravity contour map superimposed on the geography and structure in the Lower Verde River valley. (Gravitr data from Lysonski et al., 1981)
consistent with a change from more dense granitic and metamorphic rocks to sedimentary rocks across a buried fault. The gravity contours curve southeastward until they trend nearly east-west, east of the Verde-Salt confluence. This trend matches the geometry of the previously described faults in the region.

**Distribution of Lake-bed deposits**

The distribution of the Pemberton Ranch Formation (informal name), a Late Tertiary lake-bed (playa) deposit (Map unit Tsp), is shown in figure 3. From existing outcrops and well-log data it is apparent that fine-grained deposits covered a significant part of the former valley floor. Playa beds north of the Town of Fountain Hills in section 21, T. 4 N., R. 6 E., are only about 2 miles from Proterozoic bedrock in the McDowell Mountains. Well drillers' logs from Fountain Hills Monitor Well 2 (FHMW-2) and Fountain Hills Test Well 3 (FHTW-3) indicate over 200 feet of silt occur about 2 miles from bedrock outcrops. Playa deposits within a couple miles of steep bedrock outcrops have been found or occur elsewhere (see for example the modern Death Valley). However, in the north and on the east side of the Verde River near Needle Rock, more than 80 feet of fine-grained silt deposits are exposed less than ½ mile from steep granite hills. Conglomerates and coarse gravel deposits commonly form proximally to steep bedrock outcrops where steep slopes provide the energy needed to transport larger-size materials. The presence of very fine-grained material so close to bedrock is uncommon. This same relationship was observed to the east in the Tonto Basin, in the southwest corner of the Picture Mountain quadrangle, where siltstone rests directly on a very steep granite slope (Skotnicki, 1999). It is also observed on modern playas in the Death Valley region of California.

Several geologic cross-sections have been developed for the Fountain Hills Sub-basin (figure 4). These cross-sections illustrate the change in lithology that occurs throughout the basin (figure 5). In the southeast part of the basin, no silt deposits are known to occur based on bore-hole data south of Adams Mesa. This well field is within an area less than 9 sections square and data to the west and south are lacking. Bore-hole data for the goldfield Heights area reported by Thomsen and Schumann (1968) also do not show any playa deposits at depth. In the northwest part of the basin, in the 'northern
Figure 3. Probable destruction of playa deposits (informally called the Pemberton Ranch Formation) in the Lower Verde River valley.
Figure 4. Index Map showing cross-section locations in the Lower Verde River valley.
Legend

Qyr — Holocene river deposits
Qy — Holocene alluvial deposits
Tsy — Younger Sedimentary basin fill deposits
Tsm — Middle Sedimentary basin-fill deposits
Tsp — Pemberton Ranch Formation
Tsn — Needle Rock Formation
Tb — Basalt
Tc — Red beds
Yg — 1.4 Ga granites
Xg — 1.65 - 1.7 Ga granites
Xv — Matavolcanic rocks

Figure 5 Geologic Cross-Sections through Fountain Hill Sub-basin
well field’, the playa deposits appear to pinch out rather abruptly to the west and north (see cross-section B-B’ figure 5). This is consistent with the abrupt pinch out of silt beds exposed at the surface in approximately the same area near Needle Rock. So apparently the ancient Late Tertiary playa was confined on the northwest and southeast by older and/or contemporaneous basin-fill conglomerates and sandstones. But on the southwest and northeast the lake beds were deposited almost all the way up onto the bedrock.

It is not clear if the Pemberton Ranch Formation is cut by any faults. No faults are visible in exposures at the surface. The near-horizontal beds suggest the unit was deposited after tectonism in the basin. However, the Camp Creek Fault cuts the younger basin-fill sediments (map unit Tsy), which unconformably overlie the Pemberton Ranch Formation. This suggests that if the Camp Creek Fault was active in the central part of the basin, then it may have faulted the playa deposits in this area as well.

BASIN HYDROLOGY

Hydrology in the Fountain Hills sub-basin has historically been recognized as two separate components; surface water and groundwater. In reality, the hydrology of the sub-basin is more dynamic in nature, where one particle of water may be present above ground as streamflow at one moment; the next moment the same particle of water has infiltrated and is now present as groundwater in the aquifer. The opposite case is just as common, where groundwater moves upwards from the aquifer and discharges into the river (now surface water). The interaction of surface water and groundwater in the sub-basin (although hydrologically speaking is the same water) is referred to separately below in its traditional components of stream system and aquifer system.

There are at least two aquifer systems in the Fountain Hills sub-basin. The floodplain aquifer is formed by groundwater that occurs in the floodplain of the Verde River. This upper aquifer is generally observed to be above the silt deposits and strongly cemented, low-permeability conglomerates. The second aquifer system is found below the silt (and/or Pemberton Clay Formation) connected only locally to the Verde River, or floodplain aquifer, from slow percolation through the more permeable deposits occurring at the basin margins near the mountain fronts. The regional aquifer system is made up of groundwater that occurs within the conglomerate unit. Early researchers McDonald and
Padgett (1945) discussed two water wells penetrating “water-bearing conglomerates” beneath the clay, close to the center of the valley. One well, drilled 540 feet deep in the central part of the valley, was artesian and “had sufficient pressure to flow at the surface.” Recently, wells drilled for the FHSD have also demonstrated confined aquifer conditions (HSI, 2002a and 2002b). These wells drilled and constructed in the regional aquifer system exhibit water level elevations occurring at approximately 1,340 feet above mean sea level (msl).

The central part of the valley, from the Town of Fountain Hills to just south of Needle Rock, is underlain by as much as 500 feet of fine-grained silt and clay deposits of the Pemberton Ranch Formation. The unit is nearly flat-lying and undeformed. Surface exposures are weakly consolidated and hence do not exhibit a pervasive network of fractures that might act as conduits for recharge. This unit is effectively an aquiclude and little if any groundwater recharge would be expected to occur through this unit in the central part of the basin. The bedrock areas in the north, between Needle Rock and Bartlett Dam, may be logical recharge sites. Older, grussy sandstone and conglomerate (map unit Tc) are overlain by basalt flows (map unit Tb), which are in turn overlain by conglomerates of the Needle Rock Formation (map unit Tsn). The grussy sandstones are moderately to weakly consolidated and are relatively permeable, but their distribution on the surface near the river is minor and most exposures are buried beneath basalt flows. The basalt is dense and impermeable, but most outcrops are highly fractured and these fractures may provide enough permeability to allow recharge in this area. The overlying Needle Rock Formation is mostly strongly cemented by coarse-grained calcite spar and probably is not very permeable. However, the Needle Rock Formation is also locally fractured. So although the rock types exposed along the Verde River in the north are not highly permeable, fractures may allow for some recharge. More data on fracture permeability needs to be acquired before firm conclusions can be reached about recharge occurring in the north.

Mountain front recharge is a significant source of water in the Fountain Hills sub-basin, and has been estimated to be approximately 2,700 acre-feet per year (excluding Sycamore Creek) (HSI, 2002c). Mountain front recharge by definition is the water that infiltrates into the zone of coarse alluvium that extends from the base of the mountain...
into the basin. Water flows downward through the unsaturated zone in a broad band paralleling the mountain front. The width of the recharge zone is dependent on the nature and magnitude of the runoff from the consolidated rock areas. This recharge occurs near the mountain fronts at the intersection of the bedrock outcrop and alluvial surface. Two areas in the sub-basin where significant recharge is likely to occur are along Camp Creek in the north and Sycamore Creek in the eastern portion of the sub-basin.

The younger basin-fill deposits to the northwest along Camp Creek are grussy and for the most part only moderately consolidated. These deposits are deeply dissected along Camp Creek, which is a major tributary to the Verde River in the basin. Camp Creek is very wide and floored by unconsolidated sand and gravel, and the majority of flow in Camp Creek is subsurface flow. It is not known what rocks lay beneath the younger basin-fill deposits in this area, or how permeable they are.

On the east side of the valley, Sycamore Creek drains a large area of the west-central Mazatzal Mountains. The creek travels through a narrow gorge across bedrock until it enters younger basin-fill sediments just north of Adams Mesa. Here it fans out into a wide flood plain floored by unconsolidated sand and gravel. Well data show that unconsolidated deposits exist to a depth of at least 105 feet (Thomsen and Schumann, 1968). Thomsen and Schumann (1968) found that the coefficient of permeability for unconsolidated alluvium in the wash and the basin-fill deposits were very different. They calculated the hydraulic conductivity of the unconsolidated alluvium as 5,200 gpd/ft², while the hydraulic conductivity of the basin-fill deposits was only 8.3 gpd/ft². They calculated that the velocity of water in both deposits was 18.5 ft/day (6,750 ft/yr) and 0.04 ft/day (15 ft/yr), respectively. Because the unconsolidated alluvium is so permeable, less than 10% of the average runoff from the upper bedrock area of Sycamore Creek reaches the Verde River as streamflow (Thomsen and Schumann, 1968). Most of the water slowly flows to the Verde River through the subsurface unconsolidated alluvium. Very little water percolates into the underlying basin-fill deposits. From direct observation, most of the basin-fill deposits (map unit Tsy) in the valley are similarly well-cemented and probably have moderate to low permeability, especially compared to the unconsolidated alluvium.
The Verde River, which flows north to south through the sub-basin, is the primary drainage to the area and is the dominant component in the stream system. Historically the Verde River has provided water for mining, agricultural, and ranching purposes for greater than a century. Under natural conditions the flow in the Verde River would consist exclusively of runoff and baseflow. Runoff is stream flow resulting from individual rainfall events on the watershed and occasional snow melt in the surrounding mountains. Baseflow is stream flow resulting from the discharge of groundwater to the stream and is characterized by sustained low flows showing relatively little daily variation. However, the Verde River is not under a naturally flowing system, and although both baseflow and runoff are components of the flow, the sustained flow of the river in the Fountain Hills Sub-Basin is regulated and almost completely reflective of the controlled releases from Bartlett Reservoir (USGS, 2002).

Surface water measurements collected for Verde River flows from the upper stream gage at Bartlett Dam (33° 48’ 30") and the downstream gage near Fountain Hills (33° 33’ 31") for the period from 1970 to the present show that in most years the Verde River is a loosing stream. Streamflow losses may be a result of streambed infiltration, evaporation, evapotranspiration, diversions, and more recently groundwater withdrawals from wells. The losses are dependent on many variables such as amount of precipitation, temperature, relative humidity, transmissivity, amount of vegetation cover and type of plants, and others. The average losses from the Verde River over the 30 year time period (1970-1999) were approximately 7 percent.

McDonald and Padgett (1945) estimated that phreatophytes (water-loving plants—mostly mesquite) in the area transpired approximately 4,500 acre-feet of water per month, which alone may account for the losses. However, the more recent groundwater modeling study of the area suggests that groundwater consumption by phreatophytes may be less than 5,200 acre-feet per year (HSI, 2002c). This study includes phreatophytic consumption by mesquite as well as consumption of groundwater by strands of cottonwood and willow growing along the Verde River’s riparian area. The recent study addresses the fact that mesquite is an opportunistic phreatophyte (using both groundwater and surface water from precipitation events), and that most calculations of evapotranspiration of groundwater by mesquite are overestimates. The value of 5,200
acre-feet per year for evapotranspiration, although significant, does not nearly account for the losses observed along the Verde River through the Fountain Hills sub-basin. The majority of water losses from the Verde River are due to agricultural diversions to the Fort McDowell Indian Reservation and infiltration induced by nearby groundwater withdrawals from the aquifer located in the floodplain of the river.

Beginning in 1922 the City of Phoenix began withdrawing groundwater in the Lower Verde River Valley as an alternate supply of higher-quality water for the city (McDonald and Padgett, 1945). The aquifer tapped by the city at that time was very shallow and existed within Verde River gravels within about 40 feet of the surface. The wells were located just south of the confluence of the Verde River and Sycamore Creek, on an older Holocene river terrace within the flood plain of the Verde River. Recharge and supply was directly affected by fluctuating flow of the Verde River. Since initial groundwater withdrawals in 1922, water has almost continually been withdrawn from the floodplain aquifer. However, additional surface water resources have been developed with the completion of Bartlett Dam in 1939. This allowed for storage of flood-waters and controlled release of water for irrigation.

Expanding population in the area has continued the demand for more available water resources in the Fountain Hills sub-basin. Although the City Phoenix has curtailed its use of groundwater from the sub-basin since the introduction of the Central Arizona Project (CAP) water in the mid 1980’s, nearly 400 water wells have been drilled in the sub-basin since 1990 (ADWR, 2002). Many are several hundred feet deep, accessing primarily the regional aquifer system. Recent drilling under the Town of Fountain Hills and on the east side of the Fort McDowell Indian Reservation shows that the current static water level elevation is nearly the same at ~1340 feet amsl on both sides of the valley. However, this observation is based on data from only a handful of widely separated wells. The continued drilling of water wells has provided useful but limited information regarding the hydrologic system. As more well information becomes available in the area, understanding of the basin hydrology will increase.
UNITS LIKELY ENCOUNTERED IN DRILL CUTTINGS

These units have been described in previous AZGS Open-File Reports but are listed here again with some additional information to help future workers distinguish the units in drill cuttings.

Tsy  Younger sedimentary basin-fill deposits (Late Tertiary). Tan-colored, horizontally bedded, moderately sorted to poorly sorted, clast-supported sandstones and conglomerates. Fine-grained silt, sand, and pebbles are composed mostly of subangular granitic grus. Coarser cobbles and small boulders are mostly subangular to subrounded metamorphic clasts and locally granite. Outcrops south of Shea Blvd. are relatively thin, and form small, isolated exposures capping hills. Here the unit is composed of 50% sand- to boulder-size granitic clasts and cobble-size metamorphic clasts, and about 50% subrounded basalt cobbles to boulders with varnish. Northeast of McDowell Pass the unit contains abundant subrounded boulders of foliated and non-foliated granite and minor basalt. The unit everywhere is very well indurated by carbonate and forms high-standing, resistant, rounded ridges and hills.

Tsm  Middle sedimentary basin-fill deposits (Late Tertiary). Very light tan to light gray, moderately consolidated, thinly bedded, clast-supported sandstones and conglomerates. Largest clasts are about 30 cm in diameter, but sand, gravel, and small cobbles are by far the most common. There is very little silt in the matrix. Finer-grained beds are composed mostly of subangular granitic sands and gravels. Coarser beds contain subrounded, gravel- to cobble-size clasts of basalt, metamorphic rocks, and granite, but basalt clasts are the most common. Brown to red crystal-rich dacite clasts (Proterozoic?) are also abundant. The unit crumbles easily yet forms high-standing, rounded hills. The matrix is carbonate-rich and locally forms well-consolidated caliche laminae. The unit locally contains small lenses of silt several centimeters to a meter or so wide, some of which appear broken and may have been reworked into clasts.
**Tsp** Pemberton Ranch Formation (Late Tertiary). Very fine-grained, tan- to brown-colored siltstone, claystone, fine-grained sandstone, and minor coarser-grained sandstone and conglomerate. Generally, the unit is thinly bedded with bedding planes defined by fissile partings on weathered surfaces. Locally, interbedded sand layers form small lenses tens of centimeters wide. Mud cracks are visible locally. Small tubular carbonate concretions several millimeters in diameter and 1-3 cm long may be root casts or burrows. In some drill cuttings the sticky clay and silt rolls into coarse sand-size fragments. If not observed closely, these fragments can easily be misidentified as coarse siliciclastic sand. The unit commonly contains minor amounts of calcite and possibly very minor gypsum. Named by Pope (1974) as the Pemberton Silt.

**Tsn** Needle Rock Formation (Late Tertiary). Clast-supported conglomerates and debris flows composed almost entirely of subrounded clasts of basalt ranging from pebble-size to 0.5 meters across, all in a silty to sandy matrix of quartz, feldspar, and basalt. The matrix is cemented by abundant calcite spar. Medium-bedded. Bedding is visible up close but is best seen from a distance. Bedding is steeper near bedrock contacts. These deposits grade laterally into finer-grained sediments of the Pemberton Ranch Formation.

**Tc** Red beds (Middle Tertiary). Interbedded matrix-supported breccia, and clast-supported conglomerate, sandstone, and minor siltstone and limestone. Breccia layers are matrix-supported, very poorly sorted, weakly to non-bedded, and contain outsized clasts up to 10 meters across, and probably represent debris flows. Locally interbedded with and intruded by mafic volcanic rocks. Clasts include granite and metamorphic rock, and only rare basaltic rocks. In exposed outcrops this unit is cemented with silica rather than carbonate. However, red grussy conglomerate obtained from the only drill core sample in this study (HSI, 2002a) was cemented with carbonate. Thus, this unit may be cemented by carbonate at depth.
REFERENCES


Arizona Department of Water Resources (ADWR), 2002, Groundwater Registry Wells 55 database.


INTRODUCTION TO APPENDIX A

Thirteen wells were drilled within the Town of Fountain Hills as part of a recharge and recovery project of the Fountain Hills Sanitary District (FHSD). HSI was selected to locate these wells and evaluate the hydrogeology of the Fountain Hills area. Lithologic and geophysical logs were obtained from ten wells. These logs were used to develop the cross-sections provided in this appendix and to refine the basin-scale cross-sections and geologic assumptions of this open-file report. The well and site specific cross-section locations are provided in Figure A-1. A brief summary of the drilling and hydrogeologic characteristics of each well is provided in Table A-1.

LITHOLOGY AND BOREHOLE GEOPHYSICS

Explanation of Lithologic Logs

The geologist’s log of the well provides a lithologic description of the material encountered during the drilling of the well from land surface to the total depth of the borehole. Drill cuttings were collected in five to ten foot intervals from the drilling fluid entire drilling process. The drill cuttings were laid out in individual piles, each representing a specific depth.

Explanation of Borehole Geophysics

Geophysical logs are used to delineate different formations, determine estimated porosity and saturation, and to detect very small amounts of radioactive materials. The caliper log measures the size of the borehole and is used to compensate for borehole diameter differences that could affect the readings. A second caliper is run after the borehole has been reamed to determine volumes of materials including gravel pack, bentonite seal, and cement used in the final construction of the well. The gamma ray measures the amount of natural gamma radioactivity produced by the decay of an element to a more stable state. In nature, the most plentiful of the decaying elements is potassium 40 (K40). Clay and silt have high radioactivity, and sand and gravel have low radioactivity. The neutron log measures the number of hydrogen atoms in the formation. Neutrons are small neutral particles that have approximately the same mass as hydrogen.
Table A-1. Well Data

<table>
<thead>
<tr>
<th>Well ID</th>
<th>Cadastral</th>
<th>Date Drilled</th>
<th>Bore Hole Depth</th>
<th>Potentiometric Surface (measurement taken at time of well construction)</th>
<th>Elevations (amsl)</th>
<th>Probable Geologic Units Penetrated by Well*</th>
</tr>
</thead>
<tbody>
<tr>
<td>FHMW-1</td>
<td>A(3-6)23abd</td>
<td>Dec-1999</td>
<td>510'</td>
<td>1,331</td>
<td>1,520</td>
<td>Tsm, Tsp, Tsn, or Tc</td>
</tr>
<tr>
<td>FHMW-2</td>
<td>A(3-6)14cbb</td>
<td>Dec-1999</td>
<td>515'</td>
<td>1,337</td>
<td>1,600</td>
<td>Tsy, Tsp, Tsn, or Tc</td>
</tr>
<tr>
<td>FHMW-3</td>
<td>A(3-6)23dba</td>
<td>Dec-1999</td>
<td>510'</td>
<td>1,262</td>
<td>1,515</td>
<td>Tsy, Tsm, Tsn, or Tc</td>
</tr>
<tr>
<td>FHMW-4</td>
<td>A(3-6)14dbc</td>
<td>April-2000</td>
<td>745'</td>
<td>1,336</td>
<td>1,570</td>
<td>Tsy or Tsm, Tsp, Tsn, or Tc</td>
</tr>
<tr>
<td>FHMW-5</td>
<td>A(3-6)14ccd</td>
<td>April-2000</td>
<td>510'</td>
<td>1,326</td>
<td>1,580</td>
<td>Tsy or Tmy, Tsp, Tsn, or Tc</td>
</tr>
<tr>
<td>ASR-1</td>
<td>A(3-6)14cba</td>
<td>April-2001</td>
<td>760'</td>
<td>1,331</td>
<td>1,585</td>
<td>Tsp, Tsn, or Tc</td>
</tr>
<tr>
<td>ASR-2</td>
<td>A(3-6)14caa</td>
<td>May-2000</td>
<td>755'</td>
<td>1,330</td>
<td>1,570</td>
<td>Tsy or Tsm, Tsop, Tsn, or Tc</td>
</tr>
<tr>
<td>ASR-3</td>
<td>A(3-6)14cca</td>
<td>Nov-2001</td>
<td>765'</td>
<td>1,339</td>
<td>1,590</td>
<td>Tsy or Tmy, Tsp, Tsn, or Tc</td>
</tr>
<tr>
<td>ASR-4</td>
<td>A(3-6)14bdc</td>
<td>May-2000</td>
<td>760'</td>
<td>1,338</td>
<td>1,600</td>
<td>Tsp, Tsn, or Tc</td>
</tr>
<tr>
<td>TW-3</td>
<td>A(3-6)15dab</td>
<td>Nov-2000</td>
<td>835'</td>
<td>1,352</td>
<td>1,600</td>
<td>Tsp, Tsn, or Tc</td>
</tr>
</tbody>
</table>

*Units mapped by Skotnicki (1995) and listed in the order of top to bottom of well. Tmy and Tel are not described in this report.

When the neutron collides with a particle containing hydrogen (H), such as water (H₂O), it loses some of its energy and slows down. After several collisions, another particle, such as chlorine, hydrogen, or silicon will capture the particle. A detector measures the number of neutrons returning to it. If a formation has a high water content (high hydrogen content) the reading will be low, the opposite is true for low water content.

The next suite of geophysical logs use electric signals to recognize changes within the formation. Resistivity logs measure the ability of a material to impede the flow of electric current. Formations such as clay and higher salinity waters have low resistivity, while sands and gravels have high resistivity. Several electrical resistivity logs are used. Single-point resistivity (SPR) measures the resistance of rocks between two electrodes. Variation in resistance is due to changes in the conductivity of the borehole fluid. If the borehole fluid is homogeneous, the variation in resistance will be due to lithologic
changes. Short-normal and long-normal logs are used to determine the resistivity close to the borehole and away from the borehole, respectively, and presumably beyond the influence of the drilling fluid. The spontaneous potential curve (SP) measures the naturally occurring borehole potential, or voltage, that arises due to differences between the borehole fluid and the formation fluid. Because water is a good conductor of electricity, where the water is high, the conductance is high; if the water content is low, the conductance is low. The resistivity and spontaneous potential curves are usually read together and are compared. The geophysical logs for the four ASR wells and five monitor wells are found in Figures A-2 through A-11.

CROSS SECTIONS

Three geologic cross-sections shown in figure A-1 were constructed based on the lithologic logs derived from borehole drilling samples and geophysical logs collected during the drilling process. Geologic cross-section A-A’ (Figure A-12) was constructed from north to south, west of Fountain Lake. This cross-section includes, from north to south, wells ASR-4, FHMW-2, ASR-1, and FHMW-5.

Cross-section B-B’ (Figure A-13) lies from north to south, east of Fountain Lake. This cross section includes from north to south wells, ASR-2, FHMW-4, FHMW-1 and FHMW-3.

Cross-section C-C’ (Figure A-14) spans west to east and includes wells FHTW-3, FHMW-2, ASR-1, and FHMW-4.
Geophysical Logs and Lithologic Log for ASR-1

Explanation

- **Basin Fill**
- **Pemberton Silt**
- **Conglomerate**
- **14" x 0.25" Blank Stainless Steel Casing**
- **"Full-flo" louvered stainless steel well casing 120 slot size**
- **Potentiometric Surface (5/25/00)**

* The pilot borehole was reduced from 17¾-inch to 16-inch diameter at 559 feet bsls

Figure A-2
Page 31
Geophysical Logs and Lithologic Log for ASR-2

Explanation
- Basin Fill
- Pemberton Silt
- Conglomerate
- Conglomerate - Clay Rich
- 14" x 0.25" Blank Stainless Steel Casing
- 14" x 0.25" "Full-flo" louvered stainless steel well casing 120 slot size
- Potentiometric Surface (6/8/00)

Tertiary Age (1.6 - 65 mya)

Figure A-3
Page 32
Geophysical Logs

Geophysical Logs and Lithologic Log for ASR-3

General Casing Design

Explanations:
- Basin Fill
- Pemberton Silt
- Conglomerate
- Tertiary Age (1.6 - 65 mya)
- 14" x 0.25" Blank Stainless Steel Casing
- 14" x 0.25" "Full-flo" louvered stainless steel well casing
- 120 slot size
- Potentiometric Surface (4/17/02)

Figure A-4
Page 33

HydroSystems Inc.
GARY G. SMALL M.S., P.G., C.E.
2200 S. PARK LANE, SUITE 5000, TEMPE, AZ. 85281
TELEPHONE: 480-517-9000 FAX: 480-517-9049
Geophysical Logs and Lithologic Log for ASR-4

Explanation

- Basin Fill
- Pemberton Silt
- Conglomerate
- Conglomerate - Clay Rich
- 14" x 0.25" Blank Stainless Steel Casing
- 14" x 0.25" "Full-flo" louvers stainless steel well casing 120 slot size
- Potentiometric Surface (6/25/00)

Figure A-5
Page 34

HydroSystems Inc.
GARY G. SMALL M.S., P.G., C.E.I.
1220 S. PARK LANE, SUITE 5 TEMPE, AZ. 85281
TELEPHONE: 480-517-9000 FAX: 480-517-9049
Geophysical Logs & Lithologic Log of FHMW-I

Resistivity
- N16 (Ohm-m)
- N64 (Ohm-m)

SPR (Ohms)
- N16 (Ohm-m)
- N64 (Ohm-m)

SP (mV)

3-Arm Caliper
(Inches)

Gamma
(API)

Neutron
(API)

Temperature
(Degrees F)

Lithology

Explanation

- Basin Fill
- Pemberton Silt
- Conglomerate
- Potentiometric Surface (4/24/01)

Tertiary Age
(1.6 - 65 mya)

Figure A-6
Page 35
Geophysical Logs & Lithologic Log of FHMW-2

Resistivity
- N16 (Ohm-m)
- N64 (Ohm-m)

SP (Ohms)

SP (mV)

3 Arm Caliper (Inches)

Gamma (API)

Neutron (API)

Temperature (Degrees F)

Lithology

Explanations

- Tertiary Age (1.6 - 65 mya)
- Pemberton Silt
- Conglomerate
- Potentiometric Surface (4/24/01)
- Transition Zone

Figure A-7
Page 36
Geophysical Logs & Lithologic Log of FHMW-3

Resistivity
SPR (Ohms) - N16 (Ohm-m)
SPR (Ohms) - N64 (Ohm-m)
SP (mV)
3 Arm Caliper (Inches)
Gamma (API)
Neutron (API)
Temperature (Degrees)
Lithology

Explaination
- Basin Fill
- Pemberton Silt
- Conglomerate
- Potentiometric Surface (4/24/01)

Tertiary Age (1.6 - 65 mya)

Figure A-8
Page 37
Lithologic Log for FHMW-4

Explanation

- Basin Fill
- Pemberton Silt
- Conglomerate
- Conglomerate - Clay Rich
- Potentiometric Surface (6/8/00)

Tertiary Age (1.6 - 65 mya)

Not to scale

Figure A-9

Page 38
Lithologic Log of FHMW-5

Not to scale

Explanation

- Basin Fill
- Pemberton Silt
- Conglomerate

Transition Zone

Dry Age ≤ 5 mya

Potentiometric Surface (4/24/01)

Figure A-10
Page 39

HydroSystems Inc.
GARY G. SMALL M.S., P.G., C.E., P.G.
1220 S. PARK LANE, SUITE 5 TEMPE, AZ. 85281
TELEPHONE: 480-317-9050 FAX: 480-317-9049
Geophysical and Lithologic Logs for FHTW-3

Explanation
- Basin Fill
- Tertiary Age (1.6 - 65 mya)
- Pemberton Silt
- Conglomerate
- Transition Zone
- Static Water Level (7/18/00)

Figure A-II
Page 40
Fountain Hills Hydrogeologic Cross - Section A-A'

Explanation

- Basin Fill
- Pemberton Silt
- Transition Zone
- Conglomerate
- Conglomerate - Clay Rich
- Contact dashed where inferred
- Potentiometric Surface

Vertical exaggeration = 7.04x
Horizontal Scale: 1"= 0.2 Miles
Vertical Scale: 1"=150 Feet

Figure A-12
Page 41

HydroSystems Inc.
GARY G. SMALL M.S., P.G., C.E.I
1220 S. PARK LANE, SUITE S TEMPE, AZ. 85281
TELEPHONE: 480-517-9050 FAX: 480-517-9049
F
North

Fountain Hills Hydrogeologic Cross - Section B-B'

F'
South

Explanation

- Basin Fill
- Pemberton Silt
- Transition Zone
- Conglomerate
- Conglomerate - Clay Rich
- Contact dashed where inferred
- Potentiometric Surface
- Perforated Interval

Tertiary Age (1.6 - 65 mya)

Horizontal Scale: 1" = 0.25 Miles
Vertical Scale: 1" = 150 Feet
Vertical exaggeration = 8.8x

Figure A-13
Page 42
**Explanation**

- **Basin Fill**
- **Pemberton Silt**
- **Transition Zone**
- **Conglomerate**
- **Conglomerate - Clay Rich**
- **Contact dashed where inferred**
- **Potentiometric Surface**
- **Perforated Interval**

**Figure A-14**

**Page 43**

*HSI HydroSystems Inc.*

GARY G. SMALL  M.S., P.G., C.E.I
1220 S. PARK LANE, SUITE 5 TEMPE, AZ. 85281
TELEPHONE: 480-517-9050 FAX: 480-517-9040