ORIGIN, DEVELOPMENT, AND CHEMICAL CHARACTER OF A PERCHED WATER ZONE, HARQUAHALA VALLEY, ARIZONA

by

Charles G. Graf
Arizona Water Commission

INTRODUCTION

The Harquahala Valley is a dry desert basin comprising about 760 square miles in southwestern Arizona. In 1950, the groundwater resource was virtually untapped. At that time, the depth to the water table ranged from 125 feet along the axis of Centennial Wash, which drains the valley from northwest to southeast, to more than 240 feet near the mountain fronts (Metzger, 1957). The successful completion of several irrigation wells in 1951 and 1952 spurred further agricultural development, so that by 1978, over 3,000,000 acre feet of ground water had been pumped to irrigate surrounding lands. This massive withdrawal of ground water has lowered the static water level over 300 feet throughout much of the basin (Fig. 1), creating a large cone of depression into which all ground-water flow is now diverted. Well Hydrograph A (Fig. 2) typifies the rapidity of water table decline in the Harquahala Valley.

ORIGIN AND DEVELOPMENT OF PERCHED WATER TABLE

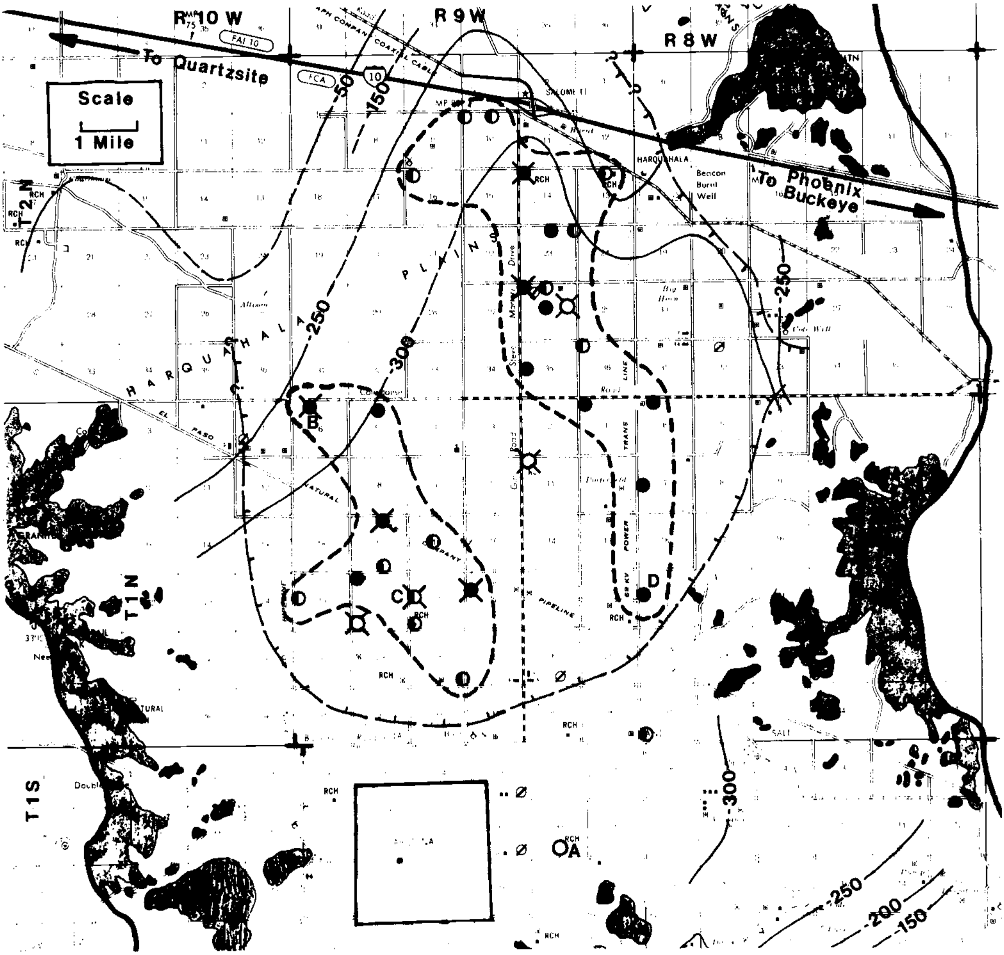
As early as 1960, anomalous water level rises and cascading water (a stream of water which issues into a well above the static water table through a casing opening and cascades downward) were noted in a few wells in the Harquahala Valley. At least 27 such wells are now known, many of them located by the author during fieldwork between January 1978 and January 1980. One pattern of water level change common to many of these wells is illustrated by Well Hydrograph B (Fig. 2). Here, the familiar decline of the static water table is interrupted by a sharp water level rise. The water level in many cases has eventually risen to an altitude above the virgin water table of the early 1950's. In other wells, measurement of the depth to the static water table has become impossible due to torrents of cascading water in the well (Well Hydrograph C). In some wells originally containing cascading water, the water level has risen hundreds of feet before stabilizing, engulfing the stream of cascading water in the process (Well Hydrograph D).

These phenomena are best explained by the development of a perched water zone. As stated earlier, water levels in wells have often climbed to an elevation higher than any historic water table, behavior not easily attributable to another cause.

Subsurface conditions are also favorable for the formation of a perched water zone. As mapped by Cooley (in Denis, 1971), fine-grained beds underlie much of the valley floor, a requisite condition for the development of a perched water zone. Not surprisingly, the wells which exhibited water level rises and cascading water cluster within the area underlain by the fine-grained deposits (Fig. 1).

Large-capacity irrigation wells in this area produce mainly from coarse materials that lie beneath the fine-grained beds. Why water levels should rise in wells drilled completely through the fine-grained beds into the coarser deposits below is still somewhat unclear. In at least some wells, collapsed well casings are known to have isolated the perched zone from the main aquifer. If water in the perched zone can then stream into the upper section of the casing through weep holes, perforations, or other openings , the water level in the well will rise until equilibrium with the surrounding perched zone is reached.

In other wells having structually sound casings, cascading water from the perched zone, possibly laden with silt and clay, collides energetically with water standing in the well at the main aquifer. The water at this surface undergoes abundant aeration and is eventually forced through the casing perforations into the adjacent formation as more water plunges down from above. Skibitzke (1978) states that in recharge



E X P L A N A T I O N

-250- APPROXIMATE LINE OF EQUAL CHANGE IN WATER LEVEL, 1953-1980--Interval 50 and 100 feet; Dashed where inferred.

APPROXIMATE AREA IN WHICH PERCHED GROUND WATER IS KNOWN TO BE PRESENT

GENERALIZED LIMIT OF FINE-GRAINED BEDS--Slightly modified from Cooley (in Denis, 1971). Queried where uncertain.

●B WELL IN WHICH PERCHED WATER IS NOW PRESENT--Letter indicates well for which hydrograph is shown in Figure 2.

◐ WELL IN WHICH CASCADING WATER IS NOW PRESENT

○ SELECTED WELL IN WHICH STATIC WATER LEVEL IS REPRESENTATIVE OF MAIN AQUIFER

WELL FOR WHICH CHEMICAL ANALYSIS IS SHOWN IN TABLE 1.

AREA OF BEDROCK OUTCROP

BOUNDARY OF HARQUAHALA VALLEY WATERSHED

Figure 1. Change in Water Level, 1953-1980, and Location of Perched Water Zones, Perched and Cascading Wells, and Fine-Grained Beds, Harquahala Valley, Arizona

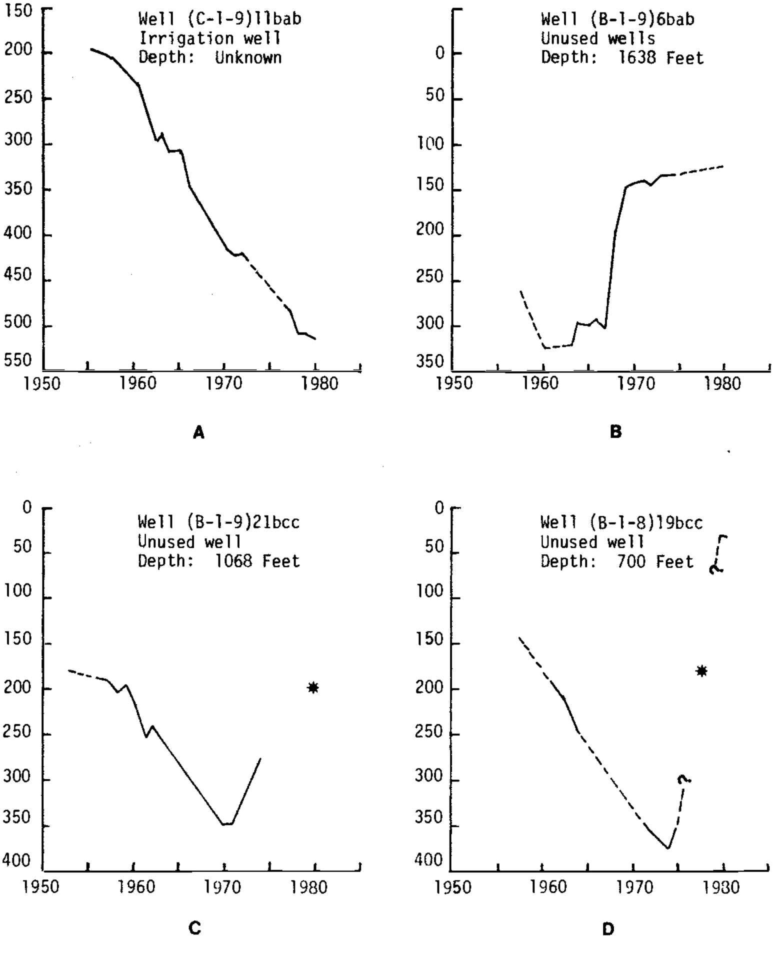


Figure 2. Hydrographs from Selected Wells in the Harquahala Valley, Arizona. (Dashed where more than two pumping seasons intervened between measurements; queried where indefinite. The symbol * represents level at which cascading water entered well; static water level could not be obtained due to interference by stream of cascading water.)

wells, one of the most severe problems is the slow but progressive clogging of the aquifer by small particles and entrapped air. A stream of cascading water must also do likewise, slowly choking the aquifer with silt and air, necessitating a gradual increase in head to maintain the same rate of discharge into the aquifer. When the aquifer finally plugs completely, the water level in the well will have risen to equilibrium with the hydrostatic head of the surrounding perched zone.

In the Harquahala Valley, the surface of the perched zone is very irregular, probably mirroring inhomogeneities in the fine-grained beds. Some of this irregularity probably can be attributed to measurement of rising water levels not yet in equilibrium with the hydrostatic head of the perched zone. Measured water levels, whether they represented the true hydrostatic head of the perched zone or were merely forerunners to it, ranged from 25 to 300 feet below land surface. Very often, nearby irrigation wells sealed from intrusion by perched water had static water levels standing 450 or more feet below land surface.

CHEMICAL CHARACTER

The presence of cascading and perched wells in an area where perched water was originally absent, but has subsequently built-up in response to irrigation seepage, afforded an excellent opportunity to study the water quality changes attendant to irrigation. A total of six water samples were collected, five from wells that had experienced water level rises and are now perched, and one from a stream of cascading water. The results of these analyses are reproduced in Table 1. Numerous samples of water from the main aquifer have been collected over the years, but only four representative analyses are shown for comparison in Table 1.

Except for one sample, the most obvious characteristic of the perched water is the increase in dissolved solids. The Total Dissolved Solids concentration of water pumped from the main aquifer varies from about 450 to 750 mg/l. Water from perched or cascading wells, however, had TDS amounts ranging from 1402 to 3567 mg/l,except for well (B-1-9) 6bab, with its anomalously low TDS concentration of 776 mg/l. The Stiff Diagrams in Figure 3 portray the increase in Total Dissolved Solids graphically and show the relative milliequivalent concentrations of the major ions. When displayed this way, the analysis for perched well (B-1-9)6bab appears nearly identical to analyses of water from the main aquifer. The reason for this similarity is not known.

The concentrations of individual ionic constituents show much greater relative variability than the total dissolved solids data suggest. These divergences underscore the complexity of the chemical, physical, and biological reactions that occur from the time water is pumped onto a field until the time it is collected in a well as a cascading stream or as a sample from a column of perched water. Dissolved sodium, chloride, and sulfate, for example, were consistently enriched in the six samples. The factor of enrichment, however, varied widely from well to well, ranging from 1.1 times to 9.2 times concentrations found in the main aquifer.

Calcium, magnesium, carbonate, and bicarbonate compose part of a much more complex chemical system; the analyses reflect the complexity of that system. In one sample, the dissolved calcium concentration was 4/10 of that found in the main aquifer, while in another sample over an eightfold enrichment of calcium was found. Magnesium and bicarbonate concentrations also varied widely, and in two samples, dissolved carbonate was present.

The concentration of nitrate showed the greatest variability of any measured component, ranging from 1 mg/l (as NO_3) to 944 mg/l. For comparison, the nitrate level in the main aquifer is between about 15 and 20 mg/l. Although much of the nitrate enrichment probably results from application of fertilizers, the reason for nitrate reduction is unclear.

Fluoride concentrations in the six samples ranged from 3.2 mg/l to 17.6 mg/l. This represents a factor of enrichment of 1.1 to 7.3 compared with the fluoride concentration in main aquifer water. In general, fluoride was concentrated to a lesser extent than sodium, chloride, and sulfate.

CONCLUSIONS

Perched water derived from the downward percolation of irrigation water has been identified in large areas of the Harquahala Valley. Against a regional backdrop of drastic water table decline, the existence of a zone of perched water was suggested primarily by (1) rising water levels, (2) absurdly high water levels, and (3) cascading

WELL DESIGNATION	DATE SAMPLED	WATER SOURCE	DEPTH TO SOURCE (ft)	SAMPLING METHOD	SPECIFIC CONDUCTANCE (umhos/cm)	TOTAL DISSOLVED SOLIDS (mg/l)	SODIUM (mg/l)	CAL-CIUM (mg/l)	MAG-NESIUM (mg/l)	CAR-BONATE (mg/l)	BICAR-BONATE (mg/l)	CHLO-RIDE (mg/l)	SUL-FATE (mg/l)	NI-TRATE (mg/l)	FLUO-RIDE (mg/l)
WELLS WITH PERCHED AND CASCADING WATER															
(B-1-9)6 bab	9-26-79	Perched	126	Bail-type sampler	1040	776	230	15	9	4.8	234	116	180	23	3.6
(B-1-9)17abb	9-26-79	Perched	82	Bail-type sampler	4000	3567	760	134	88	0	173	796	660	944	3.2
(B-1-9)21bcc	9-26-79	Cascading	195	Lowered bucket	2780	2423	680	55	40	0	198	524	440	522	4.2
(B-1-9)22bcb	9-25-79	Perched	296	Bail-type sampler	1850	1402	470	6	7	70	327	308	315	1	7.9
(B-2-9)14bbb	12-11-79	Perched	173	Small pump	3700	3126	710	289	20	0	102	630	1050	85	4.4
(B-2-9)26bbb	9-20-79	Perched	30	Bail-type sampler	>2500	3229	1140	13	3	62	366	850	810	151	17.6
SELECTED IRRIGATION WELLS PUMPING FROM THE MAIN AQUIFER															
*(B-1-9)11bbb	3-13-74	M.A.	~420	Pumped	1170	738	235	12	1.7	0	165	81	250	15	1.8
*(B-1-9)20ccc	8-07-74	M.A.	~480	Pumped	1190	641	204	16	9.1	0	267	120	110	15	2.9
*(B-2-9)14bbb	8-08-74**	M.A.	~460	Pumped	1005	589	144	32	14	0	140	120	150	21	1.6
*(B-2-9)25adc	3-08-74	M.A.	~440	Pumped	850	486	143	17	7.2	0	134	92	110	15	2.4

M.A.=Main Aquifer

*Designates sample collected and analysed by U.S. Geological Survey (total dissolved solids concentration calculated as sum of constituents; depth to source is estimated for 1974). All other samples collected by author and analysed by Arizona Department of Health Services Laboratory (total dissolved solids determined as residue at 180°C).

**Sample collected before perched water table developed in well. Compare with 12-11-79 sample from same well.

Table 1. Chemical Analyses From Wells With Perched and Cascading Water, and From the Main Aquifer, Harquahala Valley, Arizona.

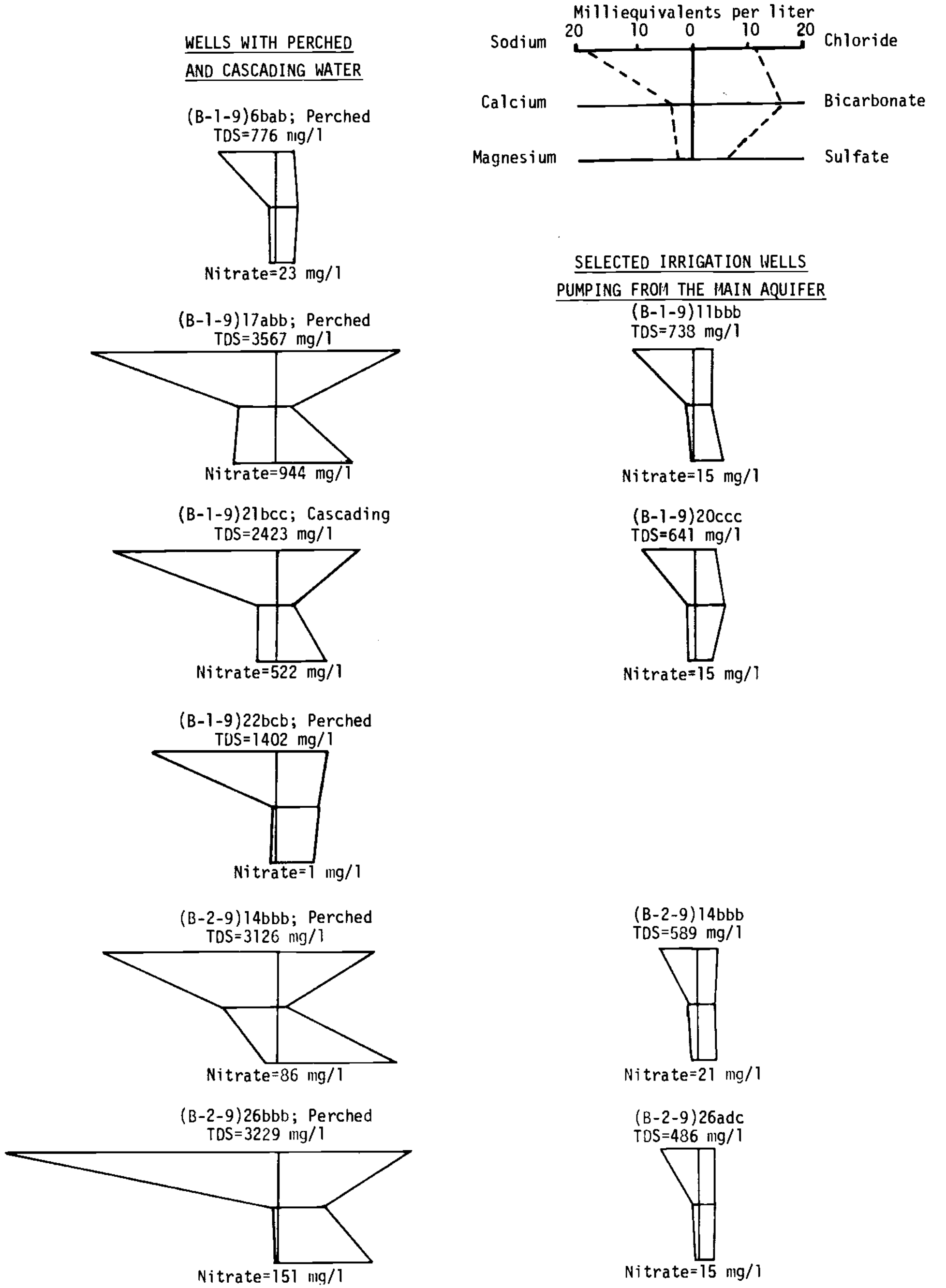


Figure 3. Stiff Diagrams of Analyses of Perched and Cascading Water, and of Water Pumped From the Main Aquifer, Harquahala Valley, Arizona.

water in wells. Samples of water from the perched zone generally showed severe deterioration of chemical quality with respect to the main aquifer, however individual constituents may be significantly attenuated or enriched. More work is needed to better characterize the quality of irrigation-derived percolating water, and to understand the reasons for dilution or concentration of individual constituents.

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