CHEMISTRY OF EFFERVESCING GROUNDWATER FROM MUNICIPAL WELLS, FLAGSTAFF, ARIZONA

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INTRODUCTION

Gases effervesce from groundwater produced from specific wells in Flagstaff's Lake Mary and Woody Mountain municipal well fields. Degassing was first noted at the Lake Mary well field in 1962 when Lake Mary well number 1 (LM-1) was placed into production, and later noted at the Woody Mountain well field in 1972 when Woody Mountain well number 5 (WM-5) was placed into production following rehabilitation. The locations of the well fields and of other sources of water for Flagstaff are shown on Figure 1.

HYDROGEOLOGICAL CONDITIONS

The Lake Mary well field is located approximately eight miles southeast of Flagstaff on the west and downthrown side of the Anderson Mesa Fault. The sequence of rock units, in descending order, at the Lake Mary well field is: alluvial and colluvial deposits, the Kaibab Limestone, the Coconino Sandstone and the Supai Formation. Subsurface hydrogeological relations at the Lake Mary well field are shown on Figure 2. The Woody Mountain well field is located about six miles southwest of Flagstaff on the east and downthrown side of the Oak Creek Fault. The sequence of rock units, in descending order, at the Woody Mountain well field is: alluvial and colluvial deposits, lava-flow rocks, the Moenkopi Formation, the Kaibab Limestone, the Coconino Sandstone, and the Supai Formation. Subsurface hydrogeological relations at the Woody Mountain well field are shown on Figure 3. Both well fields produce groundwater from the Coconino Sandstone aquifer (Harshbarger & Carollo, 1972).

Recharge to the Coconino aquifer occurs as infiltration from snow melt, from ephemeral stream flow, and from ephemeral and perennial lakes which include: Lower Lake Mary, a perennial lake adjacent to the Lake Mary well field, and Rogers Lake and Dry Lake, which are ephemeral lakes located near the Woody Mountain well field. Recharge water moves easily through the highly permeable Kaibab Limestone which contains many fractures that have been enlarged by solution. The Coconino Sandstone is poorly permeable except where extensively fractured by faulting similar to that adjacent to the Oak Creek and Anderson Mesa Faults.

CHARACTER OF EFFERVESCING GROUNDWATER

After being discharged from the well, the effervescing water appears milky with the gas remaining in suspension for several minutes. A fizzing sound is audible for a few minutes while a sample from LM-4 degases. A pulsation or surging sound is noted when the wells which produce effervescing groundwater are being pumped. Rates of effervescence change with duration of pumpage and with pump discharge rate.

Gases which effervesce from groundwater in storage in the Coconino aquifer yield bubbles that may fill interstices and may reduce permeability in the aquifer. Reduced permeability results in a decrease in specific capacity for a pumped well. Decreases in specific capacity are reported at LM-2 and are believed to result from reduction of permeability in the Coconino aquifer.

COLLECTION OF GAS SAMPLES

Samples of the effervescing gas were first collected in an evacuated 500 or 1,000 milliliter (ml) glass bulb. The bulb was connected to a faucet at the well-head with a hose which was fitted with a three-way stopcock. The stopcock was used to purge the hose of air. During collection of the sample, the bulb was filled approximately one-half full with gas-charged water. A slight residual vacuum allowed the water in the sample bulb to further degas after collection, but caused injection of the gas sample into a gas chromatograph to be difficult.

A modified procedure, in which the effervescing water was displaced by the effervesced gas, was more successful. The gas samples were later displaced with distilled water during injection

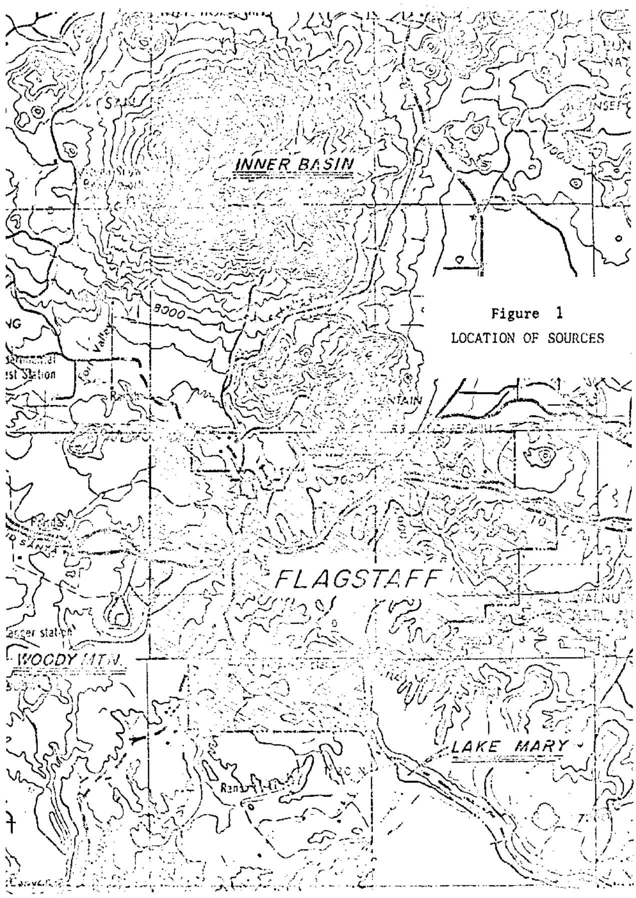

Figure 1
LOCATION OF SOURCES

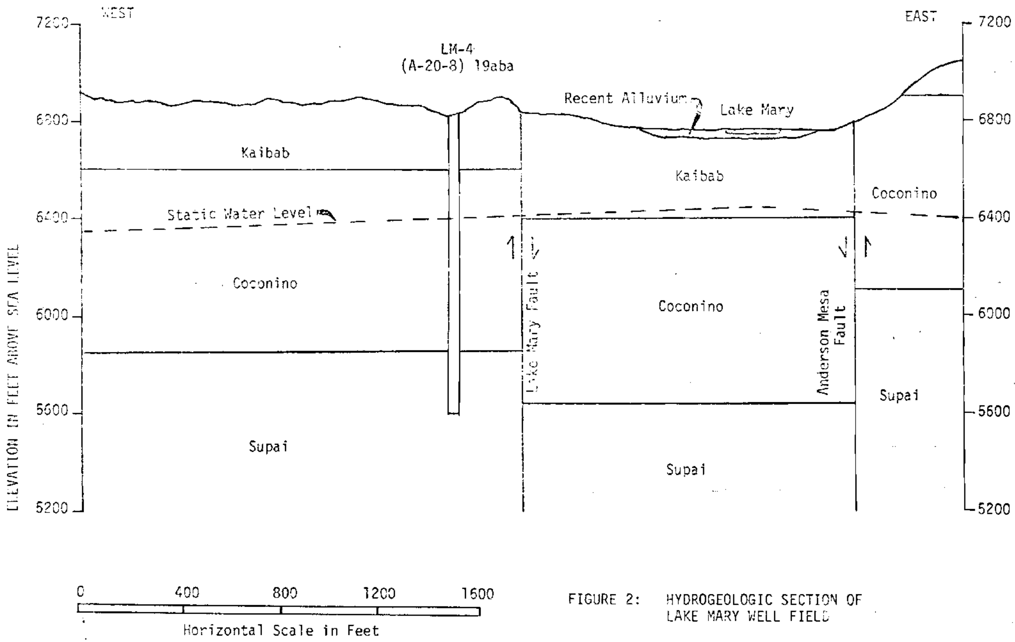

FIGURE 2: HYDROGEOLOGIC SECTION OF LAKE MARY WELL FIELD

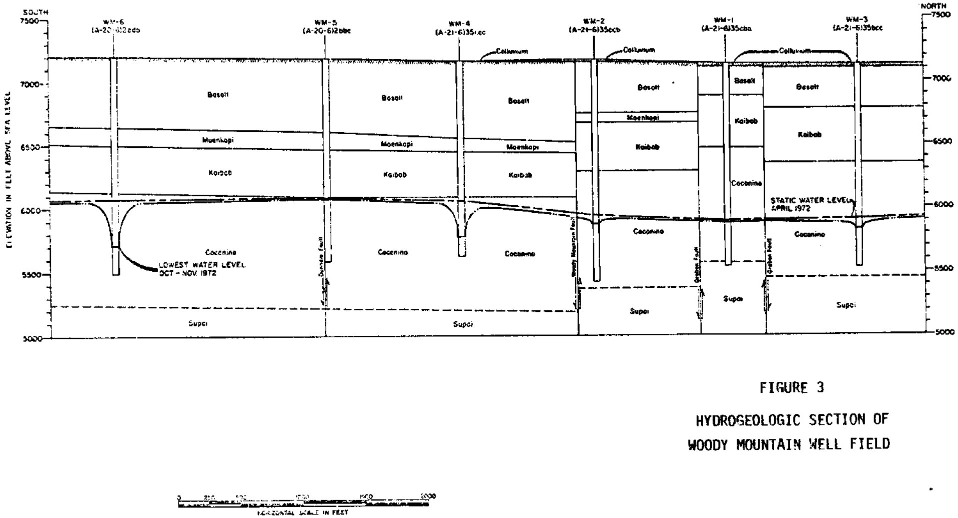

FIGURE 3

HYDROGEOLOGIC SECTION OF
WOODY MOUNTAIN WELL FIELD

into a gas chromatograph. A dead-air space which is estimated to be one-to-two milliliters is associated with each of three stopcocks and causes a slight contamination.

ANALYSIS OF GAS AND WATER SAMPLES

Initial identification of the gas was made by mass spectrometry. The principal constituents of the effervescing gas were found to be nitrogen, oxygen, and argon. Initial identification using mass spectrometry also made the design of the quantitative gas chromatographic analysis technique possible.

Gas samples from three wells (LM-2, LM-4, and WM-5) were analyzed for quantities of nitrogen, oxygen, and argon using a gas chromatograph. Air was used for the calibration standard. The results of these analyses are summarized in Table 1.

Water samples from LM-2, LM-4, WM-1, WM-4, WM-5, WM-6, Rogers Lake and Lower Lake Mary were also analyzed. Cations were quantitatively identified by atomic absorption spectrophotometry. Results of analyses of water samples are given in Table 2. Amounts of dissolved oxygen were determined using the Modified Winkler Method of iodometric titration (EPA, 1971). Amounts of dissolved carbon dioxide were calculated using results of alkalinity measurements. Results of analyses for dissolved gases are given in Table 3.

DISCUSSION

Groundwater from the Coconino Sandstone aquifer at the Flagstaff municipal well fields is classified as calcium magnesium bicarbonate sulfate water using the dominant ion classification of Davis and DeWiest (1966). The ion content of the groundwater samples is similar to other samples from the Coconino aquifer in the Flagstaff area (McGavock, 1968).

Inspection of the results of analyses of gas samples collected at Flagstaff municipal wells shows that the gas is sufficiently similar to air to indicate that the effervescence results from entrapped or dissolved atmospheric air. The source of the air is not known; however, the source is believed to be air which occurs in the upper part of the Coconino, above the water table. This air may be trapped during periods when recharge occurs, between the water table and a body of recharge water which temporarily saturates the uppermost Coconino. This mechanism may provide large hydrostatic pressures which are adequate to cause large amounts of air to go into solution. When pressures are subsequently reduced, in the area of the cone of depression around a pumped well or in the discharge column of a pumped well, the dissolved air comes out of solution.

Lake Mary is a principal source of recharge and may provide conditions during recharge for entrapment of air in the uppermost Coconino. All Lake Mary wells lie down-gradient from this recharge source and all Lake Mary wells pump effervescing groundwater. Rogers Lake is believed to be a local recharge center for the Woody Mountain well field and may provide air entrapment conditions. The Woody Mountain wells which lie directly down-gradient from Rogers Lake do not pump effervescing groundwater; however, WM-5 does pump effervescing water and penetrates rocks which are fractured adjacent to the Dunnam fault which is believed to provide a high permeability path through the Coconino Sandstone from Rogers Lake to WM-5.

CONCLUSIONS

The salient conclusions which have resulted from this study are:

1) Gas which effervesces from groundwater from Flagstaff municipal wells is derived from dissolved atmospheric air.
2) Groundwater from the Coconino aquifer at the Flagstaff municipal wells is classified as calcium magnesium bicarbonate sulfate water and is similar to groundwater pumped from the Coconino aquifer by other wells in the Flagstaff area.
3) The source of the gas which effervesces from groundwater pumped by the municipal wells is believed to be air which is trapped in the Coconino aquifer during recharge.

TABLE 1

Results of Gas Analyses in Volume Percent

DATE OF COLLECTION	WELL	NITROGEN	OXYGEN	ARGON
14 Mar 75	LM-2	76.5	22.6	0.90
21 Mar 75	LM-2	76.7	22.2	1.1
27 Mar 75	LM-2	77.8	20.8	0.99
19 Apr 75	LM-2	78.1	21.0	0.88
25 Apr 75	LM-2	78.8	20.2	0.96
29 Apr 75	LM-2	76.5	21.1	1.2
8 May 75	LM-2	76.3	21.8	1.9
12 May 75	LM-2	81.0	17.9	1.1
18 Apr 75	LM-4	88.0	11.0	0.99
22 Apr 75	LM-4	87.5	10.1	0.96
25 Apr 75	LM-4	89.2	9.9	0.89
29 Apr 75	LM-4	88.4	9.4	1.01
8 May 75	LM-4	87.3	11.7	1.0
12 May 75	LM-4	89.8	9.0	1.2
3 Apr 75	WM-5	81.3	17.5	1.2
15 Apr 75	WM-5	77.8	20.8	1.3
16 Apr 75	WM-5	79.9	19.0	1.1
17 Apr 75	WM-5	79.2	19.8	0.95
12 May 75	WM-5	82.2	16.6	1.0

Table 2 Results of Water Analyses in Milligrams per Liter

DATE OF COLLECTION	SOURCE	TEMP. (C)	Na	K	Ca	Mg	Fe	Mn	pH	HARDNESS (as Ca,Mg)
25 Apr 75	LM-2	10.0	6.6	2.5	62	40	0.1	0.17	8.15	320
29 Apr 75	LM-2	10.0	6.6	2.5	58	37	0.1	0.27	7.95	300
7 May 75	LM-2	10.0	6.8	3.0	62	38	0.1	0.1	8.20	310
12 May 75	LM-2	10.0	6.7	2.7	58	46	0.1	0.1	7.70	340
22 Apr 75	LM-4	10.5	2.7	2.5	28	14	0.1	0.21	8.25	125
25 Apr 75	LM-4	10.5	2.4	2.5	26	16	0.1	0.16	8.30	130
29 Apr 75	LM-4	10.5	3.2	2.5	24	15	0.1	0.22	8.05	120
7 May 75	LM-4	10.5	3.3	2.6	29	14	0.1	0.10	8.40	130
12 May 75	LM-4	10.5	3.7	2.5	25	18	0.1	0.1	8.00	140
1 May 75	WM-1	11.0	6.8	3.1	19	12	0.1	0.5	8.30	98
8 May 75	WM-1	11.0	5.9	2.5	21	12	0.1	0.3	8.30	100
12 May 75	WM-1	10.5	5.8	3.0	16	14	0.1	0.1	8.55	98
8 May 75	WM-4	11.0	6.9	3.7	22	11	0.1	0.3	7.75	100
12 May 75	WM-4	10.0	6.8	2.7	14	14	0.1	0.4	8.50	93
12 May 75	WM-5	11.5	5.6	2.7	13	14	0.1	0.4	8.30	91
1 May 75	WM-6	12.0	6.0	3.1	10	11	0.1	0.3	8.30	71
8 May 75	WM-6	12.5	6.5	3.4	19	11	0.1	0.3	8.30	93
12 May 75	WM-6	11.5	5.6	3.2	15	10	0.1	0.4	8.00	79
1 May 75	Rogers Lake	15.7	4.0	3.2	7.1	7	0.1	0.3	8.25	47
8 May 75	Rogers Lake	21.5	4.1	5.5	9.4	8	0.1	0.1	8.10	57
12 May 75	Rogers Lake	23.5	4.4	5.5	5.9	9	0.1	0.2	8.10	52
7 May 75	Lower Lake Mary	19.0	2.8	2.5	13	6	0.1	0.1	9.50	58
12 May 75	Lower Lake Mary	23.0	2.7	2.5	9.4	10	0.1	0.4	9.80	65

Table 3 Results of Analyses for Dissolved Oxygen and Carbon Dioxide in Milligrams per Liter

DATE OF COLLECTION	SOURCE	OXYGEN	CARBON DIOXIDE
25 Apr 75	LM-2	N.D.	5.1
29 Apr 75	LM-2	N.D.	8.1
7 May 75	LM-2	26.9	4.6
12 May 75	LM-2	28.0	7.1
22 Apr 75	LM-4	N.D.	1.5
25 Apr 75	LM-4	N.D.	1.3
29 Apr 75	LM-4	N.D.	2.5
7 May 75	LM-4	17.8	1.1
12 May 75	LM-4	11.7	1.4
1 May 75	WM-1	N.D.	1.1
8 May 75	WM-1	21.7	1.7
12 May 75	WM-1	21.5	1.1
8 May 75	WM-4	20.7	1.1
12 May 75	WM-4	20.4	1.1
8 May 75	WM-5	26.7	1.2
1 May 75	WM-6	N.D.	1.0
8 May 75	WM-6	23.1	1.1
12 May 75	WM-6	21.0	1.6
1 May 75	Rogers Lake	N.D.	0.4
8 May 75	Rogers Lake	20.7	0.7
12 May 75	Rogers Lake	22.0	0.4
7 May 75	Lower Lake Mary	24.7	0.1
12 May 75	Lower Lake Mary	24.7	0.1

N.D. = Quantity Not Determined

REFERENCES CITED

Davis, S. N.; and DeWiest, R. J. M.; 1966, Hydrogeology: John Wily & Sons, Inc., New York

Environmental Protection Agency; 1971, Methods for chemical analysis of water and waste: Superintendent of Documents, U.S. Government Printing Office, Washington, D.C.

Harshbarger & Associates and John Carollo Engineers, 1972, Water Resources Report - City of Flagstaff, Arizona

McGavock, E. H., 1968, Basic ground-water data for southern Coconino County, Arizona: Arizona State Land Department Water Resources Report No. 33