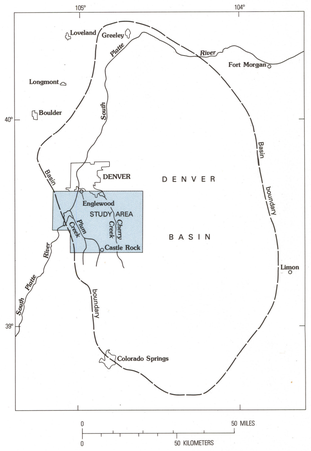
DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE
COLORADO DIVISION OF WATER RESOURCES,
OFFICE OF THE STATE ENGINEER

MISCELLANEOUS INVESTIGATIONS SERIES
MAP I–1043 (SHEET 1 OF 2)

INTRODUCTION

Population growth in the Denver metropolitan area has increased the demand for dependable supplies of water on a long-term basis. Although some water is supplied to users in the northwestern part of the Englewood-Castle Rock area (index map) by Denver's municipal water system, ground water is the primary source of water for municipalities, industries, farms, homes, and new housing developments in most of the area. The Arapahoe aquifer, one of four bedrock aquifers underlying the area, has been extensively developed since the 1950's. In the north-central and western parts of the study area, the confined Arapahoe aquifer has been intensely pumped resulting in a decline of the potentiometric surface as water is removed from storage.



PURPOSE

The purpose of the study was to determine the physical and hydraulic characteristics of the Arapahoe aquifer, and the chemical characteristics of the water. The results of the study, which was cooperatively funded by the Colorado Division of Water Resources, Office of the State Engineer, will be used by State and local officials to manage more effectively the water resources of the Arapahoe aquifer in the Englewood-Castle Rock area.

METHOD OF STUDY

The areal extent and the altitude of the base of the Arapahoe aquifer in the study area were defined using maps in a report by Romero (1976). The outcrop-subcrop area (area where aquifer crops out or where former outcrops are now covered by alluvial deposits of Quaternary age) of the aquifer was delineated using the geologic mapping of Chase and McConaghy (1972) as a guide.

The depth to the base of the aquifer was calculated by subtracting the altitude of the base of the aquifer as mapped by Romero (1976) from the altitude of the land surface. The aggregate-sand thickness (sum of the thicknesses of individual sand and conglomerate beds) was determined by examining 111 electric and lithologic logs. Electric logs were used, when available, in preference to lithologic logs because the aggregate-sand thickness could be determined more accurately. Most of the largest aggregate-sand thicknesses in the central part of the study area were determined from lithologic logs.

The chemical characteristics of water in the aquifer were determined from a total of 39 chemical analyses; 18 analyses were from samples collected during the study, 5 analyses were reported by McConaghy, Chase, Boettcher, and Major (1964), and 16 analyses were provided by well owners or ground-water consultants for samples analyzed by private laboratories. When two analyses of samples collected at different times were available for the same well, both are presented for comparison purposes.

The potentiometric-surface map for 1965 is based on the authors' interpretation of historical water levels measured in 44 wells during the late 1950's and early 1960's through 1965. The interpretation was necessary because water-level data for the single year 1965 were insufficient to describe the potentiometric surface.

The potentiometric-surface map for 1975 is based on 60 water-level measurements obtained during the study. The areas of decline of the potentiometric surface were determined by calculating the difference in the altitudes of the 1965 and 1975 potentiometric surfaces.

Most of the data for hydraulic characteristics of the aquifer were extracted from data provided by the Office of the State Engineer, ground-water consultants, and well owners. The authors made one aquifer test during the study to determine a value for the storage coefficient for the aquifer.

Few data exist in the extreme eastern and southeastern parts of the study area. Therefore, interpretations shown for these areas were extrapolated from the data in the adjacent parts of the study area.

ACKNOWLEDGMENTS

The authors thank the personnel of the Colorado Division of Water Resources, Office of the State Engineer, especially Messrs. John Romero and Harold Simpson, and the many ground-water consultants contacted during the course of the study for providing lithologic logs, electric logs, chemical analyses, and aquifer-test data. The authors also thank the many well owners who provided information regarding their wells and who permitted access to their wells for the purpose of obtaining water samples for chemical analysis, water-level measurements, and aquifer-test data.

PHYSICAL CHARACTERISTICS

The confined Arapahoe aquifer is one of four bedrock aquifers underlying the Denver Basin (index map), a structural basin whose major axis trends north and whose deposits of clay and coarser materials are thickest southeast of Castle Rock. The Dawson and Denver aquifers overlie the Arapahoe, and the Laramie-Fox Hills aquifer underlies the Arapahoe. All the bedrock aquifers consist of interbedded clay and coarse deposits that readily yield water to wells. The clay beds separating the aquifers can be as much as several hundred feet thick; they are confining beds that inhibit movement of water, so that water in the aquifers is under artesian pressure in most localities.

The Arapahoe aquifer consists of the sand and conglomerate beds, which are interbedded with clay, in the 500- to 600-foot (150- to 180-m) thick Arapahoe Formation of Late Cretaceous age as defined by Romero (1976). Along the outcrop-subcrop area, the beds dip generally 40 to 60° to the east, but locally may be vertical or overturned. East of the outcrop-subcrop area, the beds dip toward the axis of the basin at 15 to 60 ft/mi (3 to 11 m/km). In the upper 100 to 400 ft (30 to 120 m) of the formation, the beds comprising the aquifer consist of fine to coarse sand. In the lower 100 to 200 ft (30 to 60 m) of the formation, the beds comprising the aquifer consist of conglomerates, conglomeratic sands, and coarse sand. Most of the beds comprising the aquifer, particularly in the upper part of the formation, are lenticular. However, some beds comprising the aquifer in the lower part of the formation are areally extensive. The degree of horizontal and vertical interconnection of the beds comprising the aquifer increases from the upper part to the lower part of the formation.

The aggregate-sand thickness ranges from less than 100 ft (30 m) in the northwest part of the study area to 560 ft (170 m) in the central part of the area as shown on the aggregate-sand thickness map. The greatest aggregate-sand thicknesses occur in a northeast-trending band from near Louviers to east of Interstate Highway I–25.

The depth to the base of the Arapahoe aquifer is controlled by the altitude of the land surface and the structure of the basin. East of the outcrop-subcrop area, the depth ranges from about 500 ft (150 m) under Chatfield Lake to about 2,500 ft (760 m) along the southern boundary of the study area near Castle Rock. Depth to the base of the aquifer, in the study area, is greatest under the highlands and least along the channels of the principal streams: the South Platte River, Cherry Creek, and Plum Creek. (See map showing depth to the base of the aquifer.)

The map showing the aggregate-sand thickness and the depth to the base of the aquifer can be used by landowners and well drillers to obtain an approximation of the magnitude of well yield. Generally, the greater the sand thickness, the greater the well yield will be. The map also can be used to determine the feasibility and approximate cost of drilling a well that will penetrate the full thickness of the Arapahoe aquifer.

WATER-QUALITY CHARACTERISTICS

GENERAL WATER QUALITY

Two types of water, calcium bicarbonate and sodium bicarbonate, occur in the Arapahoe aquifer in most of the study area. A calcium sulfate or a sodium sulfate type occurs in the northwestern part of the study area. The general geographic occurrence of the water types is shown on the map of water-quality characteristics.

Calcium bicarbonate type water occurs in the outcrop-subcrop area throughout the study area and is the result of water percolating through the outcrop-subcrop area and dissolving calcium carbonate cement in some of the aquifer beds. As the water moves through the outcrop-subcrop area and then downgradient into the basin, the calcium bicarbonate water is affected by the interaction of two processes: (1) Ion exchange, the process by which calcium ions are replaced by sodium ions, as the calcium bicarbonate water comes into contact with weathered clays; and (2) mixing with sodium bicarbonate water existing in the aquifer or mixing with calcium bicarbonate or sodium bicarbonate water percolating downward into the Arapahoe from the overlying Denver aquifer.

The interaction of the two processes, which can accelerate or inhibit the change from calcium bicarbonate water to sodium bicarbonate water, is dependent on the geohydrologic characteristics of the Arapahoe aquifer and the overlying Denver aquifer at different places in the study area. In the Chatfield Lake area, the Arapahoe consists principally of clay that increases the rate of ion exchange. Water percolating downward from the overlying Denver aquifer is probably a sodium bicarbonate type. The result is that the calcium bicarbonate water moving from the outcrop-subcrop area is changed to a sodium bicarbonate water adjacent to the outcrop-subcrop area. In contrast, the Arapahoe in the southwestern part of the study area consists principally of sand that inhibits the rate of ion exchange. Water percolating downward from the overlying Denver aquifer is probably a calcium bicarbonate type (McConaghy and others, 1964). The result is that calcium bicarbonate type water persists in the Arapahoe aquifer farther from the outcrop-subcrop area.

In the northwestern part of the study area, sulfate predominates over bicarbonate, resulting in a calcium sulfate or a sodium sulfate type water. The predominance of sulfate is probably the result of oxidation of pyrite or organic material occurring in the clays in this area.

Most constituents in the water do not exceed the standards established for drinking water by the Colorado Department of Health (1971) as indicated by the data in the table of chemical analyses. As classified by the U.S. Geological Survey, most of the water is soft or moderately hard as summarized in the table below.

Hardness, as calcium carbonate, in milligrams per liter	Classification	Number of samples[1]
Less than 60	Soft	15
60 to 120	Moderately hard	17
120 to 180	Hard	3
Greater than 180	Very hard	3

[1] Does not include 1972 sample for well 22.

The map showing water-quality characteristics and the table of chemical analyses can be used by landowners and well drillers to predict the type and general chemical characteristics of water that will be produced by a well completed in the Arapahoe aquifer. The landowner also can determine if a water softener to remove excess hardness will be needed, depending on the intended use of the water.

WATER-QUALITY PROBLEMS

Water-quality problems in the study area are relatively minor. Dissolved solids, fluoride, iron, manganese, and sulfate occur locally in concentrations greater than those recommended by the Colorado Department of Health (1971) for drinking water. Hardness may be a problem, depending on the use of the water.

Dissolved-solids concentration exceeds the recommended limit of 500 mg/l (milligrams per liter) in four samples. The maximum dissolved-solids concentration is 740 mg/l. The principal effect of high dissolved-solids concentrations is that a noticeable taste is imparted to the water. High dissolved-solids concentrations also increase the possibility that individual constituents may exceed their recommended limits for drinking water.

Fluoride concentration exceeds the recommended upper limit of 1.3 mg/l, based on the annual average of maximum daily air temperatures, in 13 samples. The maximum fluoride concentration is 3.1 mg/l. According to the Colorado Department of Health (1971), the lower limit for fluoride, below which the probability of tooth decay increases, is 0.7 mg/l; the optimum concentration, at which tooth decay is prevented, is 0.9 mg/l. Fluoride concentrations above the recommended upper limit can cause mottling of teeth (fluorosis), especially in children.

Both iron and manganese locally exceed recommended limits for drinking water. Iron concentration exceeds the recommended limit of 300 μg/l (micrograms per liter) in seven samples. The maximum iron concentration is 1,700 μg/l. Manganese concentration exceeds the recommended limit of 50μg/l in five samples. The maximum manganese concentration is 320 μg/l. The principal effects of high iron and manganese concentrations in water are staining of laundry and porcelain fixtures, and imparting a bitter taste to beverages, such as coffee and tea. The high concentrations of iron and manganese found in the water in the study area do not constitute a health hazard.

Sulfate concentration exceeds the recommended limit of 250 mg/l in two samples. The maximum sulfate concentrations is 360 mg/l. The principal effect of high sulfate concentrations is that people drinking the water may suffer from gastrointestinal disorders, such as diarrhea.

Whether or not hardness is a problem depends principally on the use of the water. A comprehensive summary of limiting or recommended concentrations for domestic, industrial, and agricultural uses is found in McKee and Wolf (1963, p. 195–197). Selected limits or recommended concentrations for uses that may be applicable to the study area are summarized below (adapted from McKee and Wolf, 1963, p. 196–197):

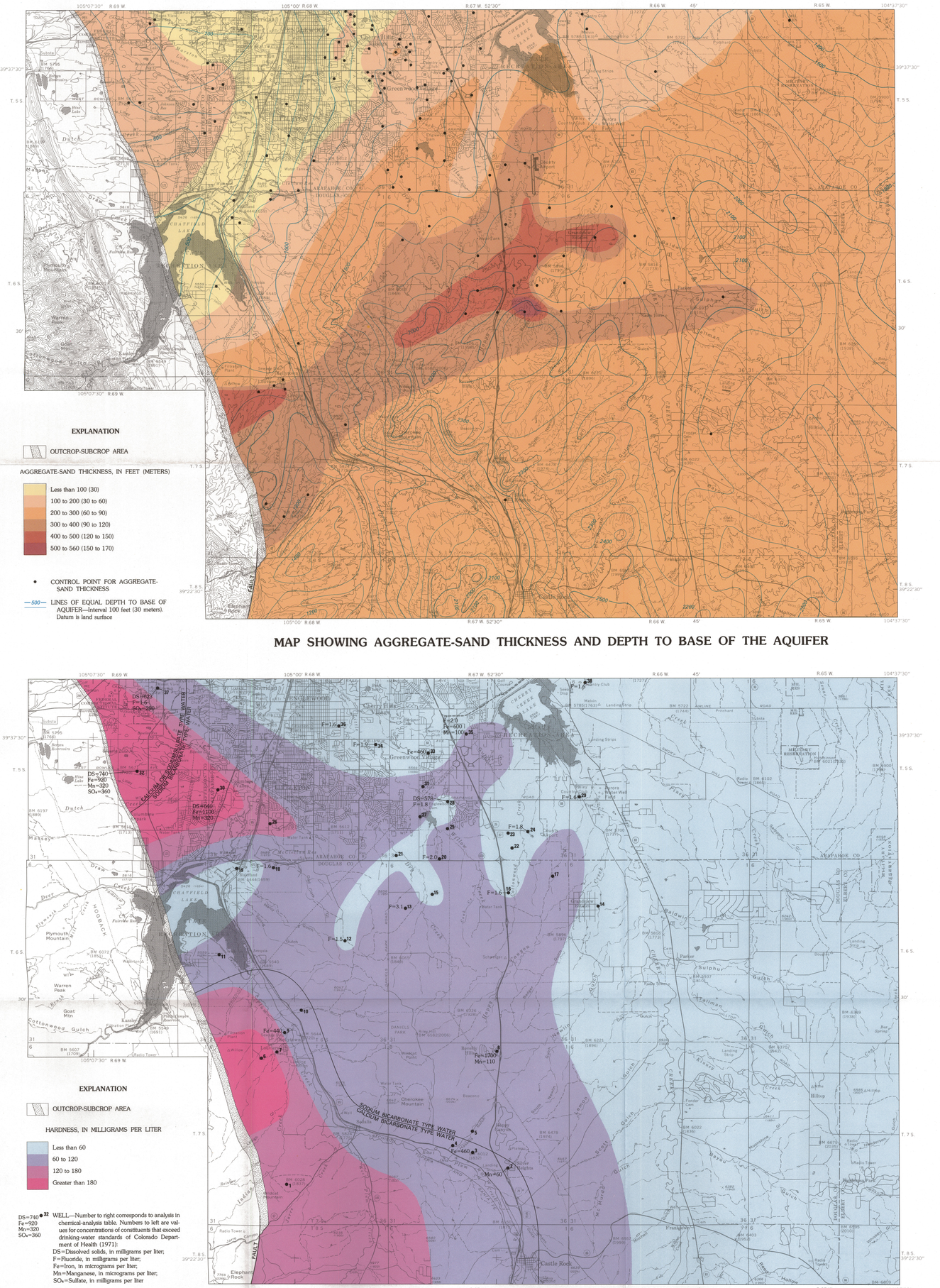
Industry and process	Limiting or recommended values of hardness, in milligrams per liter
Boiler feed water (operating pressure):	
At 0 to 150 pounds per square inch	80
At 150 to 250 pounds per square inch	40
At 250 to 400 pounds per square inch	12
At more than 400 pounds per square inch	2
Cooling	50
Food canning and freezing:	
General	50 to 85
Legumes (except peas)	25 to 75
Fruits and vegetables (except peas)	100 to 200
Peas	200 to 400
Laundering	0 to 50

SUMMARY OF CHEMICAL ANALYSES

[Drinking-water standards of Colorado Department of Health (1971) and constituents exceeding standards shown in red; mg/l=milligrams per liter, µg/l=micrograms per liter]

Map no.	Station number	Date of sample	Dissolved Silica (SiO_2) (mg/l)	Dissolved Iron (Fe) (µg/l)	Dissolved Manganese (Mn) (µg/l)	Dissolved Calcium (Ca) (mg/l)	Dissolved Magnesium (Mg) (mg/l)	Dissolved Sodium (Na) (mg/l)	Dissolved Potassium (K) (mg/l)	Bicarbonate (HCO_3) (mg/l)	Carbonate (CO_3) (mg/l)	Alkalinity as ($CaCO_3$) (mg/l)	Dissolved Sulfate (SO_4) (mg/l)	Dissolved Chloride (Cl) (mg/l)	Dissolved Fluoride (F) (mg/l)	Total Nitrate (NO_3) (mg/l)	Dissolved Nitrite Plus Nitrate (N) (mg/l)	Phosphate (PO_4) (mg/l)	Dissolved Ortho-Phosphorus (P) (mg/l)	Dissolved Solids (Sum of Constituents) (mg/l)	Hardness (Ca, Mg) (mg/l)	Noncarbonate hardness (mg/l)	Percent Sodium	Sodium Adsorption Ratio	Specific conductance (Micromhos)	pH (units)	Temperature (Deg C)	Dissolved Arsenic (As) (µg/l)	Dissolved Boron (B) (µg/l)	Dissolved Selenium (Se) (µg/l)	Laboratory making analysis
			None	300	50	None	125	None	None	None	None	None	250	250	1.3	45	10	None	None	500	None	None	None	None	None	None	10	1000	10	
1	392439105001701	75-12-17	13	10	50	52	2.8	11	2.9	173	0	142	26	1.3	1.2	--	0.02	--	0.00	196	140	0	14	0.4	345	7.5	13.0	0	30	0	USGS[1]
2	392527104510201	75-12-29	11	280	60	35	3.5	7.3	3.9	123	0	101	19	.3	.6	--	.00	--	.00	142	100	1	13	.3	200	8.2	22.0	0	30	0	Do.
3	392533104532101	74-01-29	11	480	--	34	6.6	15	--	120	<0	98	22	17	.2	.10	--	<.10	--	165	112	14	--	.6	--	8.0	--	--	--	--	Private
4	392544104540901	72-10-18	10	100	--	36	2.4	28	--	140	<0	115	20	18	.6	.20	--	<.10	--	184	100	0	--	1.2	--	7.4	--	--	--	--	Do.
5	392610104532301	74-03-08	11	80	--	36	2.0	48	--	160	0	134	17	22	.6	.20	--	.10	--	216	96	0	--	2.1	--	7.9	--	--	--	--	Do.
6	392614105010901	75-12-16	11	30	20	78	5.3	22	4.9	236	0	194	78	1.8	.9	--	.09	--	.00	319	220	23	18	.7	535	7.5	17.0	0	40	0	USGS
7	392826105004101	75-12-15	10	140	20	64	1.8	18	4.9	191	0	157	51	1.4	1.2	--	.13	--	.01	247	170	11	18	.6	375	7.6	13.0	0	40	0	Do.
8	392827104522501	59-10-13	7.0	1700	110	26	1.0	34	4.0	144	--	118	21	2.0	1.0	.00	--	--	--	167	69	0	50	1.8	278	7.9	--	--	--	--	Do.
9	392858105002201	58-02-26	14	[2]640	0	42	2.9	32	5.0	160	--	131	58	1.0	1.1	1.7	--	--	--	237	117	0	36	1.3	373	7.8	15.0	--	--	--	Do.
10	392858105004401	75-12-16	11	10	40	40	.9	12	4.0	143	0	117	22	1.1	1.0	--	.04	--	.00	164	100	0	21	.6	285	7.5	14.5	9	60	0	Do.
11	393116105025001	76-02-19	8.2	0	20	24	2.3	49	4.8	159	0	130	53	2.5	1.3	--	.29	--	.00	225	69	0	59	2.6	390	7.8	5.0	2	50	0	Do.
12	393141104580701	76-01-27	9.8	90	40	19	2.1	38	4.6	153	0	126	13	2.2	1.5	--	.01	--	.01	188	56	0	57	2.2	265	8.2	16.0	1	50	1	Do.
13	393234105055401	74-08-14	12	<50	--	26	4.0	36	--	146	<0	120	15	3.0	3.1	<.10	--	.20	--	171	82	0	--	1.7	--	7.9	--	--	--	--	Do.
14	393238104484101	74-10-04	12	70	--	16	3.2	40	--	115	24	90	23	14	.8	<.10	--	<.10	--	187	54	0	--	2.4	--	8.0	18.0	1	40	0	USGS
15	393257104545100	76-02-09	8.5	20	10	14	1.8	38	2.7	135	0	111	17	1.1	1.1	--	.18	--	.00	152	42	0	64	2.5	245	8.0	18.0	1	40	0	Do.
16	393302104515901	74-07-13	15	90	--	23	1.0	49	--	120	1	100	24	12	1.6	<.10	--	<.10	--	186	57	0	--	2.3	--	7.8	--	--	--	--	Private
17	393330104502301	74-09-15	12	<50	--	22	3.4	43	--	140	<0	115	19	8.1	1.0	<.10	--	<.10	--	177	69	0	--	2.3	--	7.8	--	--	--	--	Do.
18	393347105004600	76-02-10	8.8	10	50	22	2.5	32	3.8	154	0	126	15	1.7	1.6	--	.01	--	.00	163	65	0	50	1.7	257	8.3	7.0	1	40	0	USGS
19	393348104580201	76-01-26	11	140	50	19	1.1	34	6.3	136	0	112	18	1.5	1.1	--	.01	--	.00	159	52	0	55	2.1	245	7.8	22.0	0	40	0	USGS
20	393418104515701	72-07-13	12	100	<50	16	3.0	44	.0	110	12	110	20	13	1.0	.30	--	--	--	176	53	0	65	2.6	250	8.1	--	0	500	--	Private
21	Do.	72-12-28	12	90	30	17	1.9	38	3.2	137	0	112	18	.9	1.2	--	.00	--	.00	160	50	0	60	2.3	250	8.4	19.5	0	40	0	Do.
22	Do.	73-12-28	12	90	30	17	1.9	38	3.2	137	0	112	18	.9	1.2	--	.00	--	.00	160	50	0	60	2.3	250	8.0	26.0	0	200	--	Private
23	393445104520501	72-08-05	12	50	<50	16	3.2	42	.1	100	15	107	20	13	1.0	.10	--	--	--	200	55	0	64	2.7	250	7.6	24.0	0	500	--	Do.
24	393448104511701	72-08-26	11	100	<50	19	2.0	47	2.0	139	1	108	32	15	1.8	.10	--	--	--	200	55	0	64	2.7	250	7.6	24.0	0	500	--	Do.
25	393451104541401	74-06-15	11	<50	--	15	6.5	39	--	130	25	108	22	15	1.2	.60	--	<.10	--	199	64	0	--	2.1	--	8.2	--	--	--	--	Do.
26	393502105005501	76-05-03	6.8	20	0	35	12	35	2.6	126	0	103	61	42	1.1	--	.27	--	.00	259	140	33	35	1.3	415	7.8	12.0	1	200	0	USGS
27	393510104551901	74-07-10	11	<50	--	25	1.3	62	--	140	<0	115	20	46	1.0	.40	--	<.10	--	235	68	0	--	3.3	--	7.7	--	--	--	--	Private
28	393541104541401	74-06-25	12	<50	--	18	11	203	--	380	24	352	82	39	1.8	1.6	.00	--	--	578	244	0	--	9.3	--	8.1	--	--	--	--	Private
29	393547104492301	60-10-03	13	190	0	19	1.6	35	--	140	--	115	19	1.8	1.6	.00	--	--	--	160	54	0	54	2.1	263	7.6	19.0	--	--	--	Do.
30	393601105025901	76-04-26	11	1100	320	82	4.8	140	2.2	369	0	303	190	25	1.0	--	.01	--	.05	640	220	0	55	3.8	795	7.9	15.0	9	170	0	Do.
31	393607104551201	74-06-03	13	<50	--	23	54	64	--	98	24	120	30	35	1.1	<.10	--	<.10	--	292	80	0	--	1.7	--	7.7	--	--	--	--	Private
32	393632105005801	76-05-04	7.4	920	320	110	25	88	4.8	265	0	217	360	12	.6	--	.01	--	.01	740	380	160	33	2.0	770	7.7	14.0	9	120	0	USGS
33	393701104550001	60-09-16	12	460	20	14	.7	45	--	144	--	118	17	1.9	1.3	.00	--	--	--	183	38	0	69	3.2	274	7.2	22.5	--	--	--	Do.
34	393717104565001	76-04-26	10	250	10	7.6	.4	68	2.2	181	0	148	17	1.8	1.9	--	.00	--	.02	199	21	0	86	6.5	230	8.6	19.0	0	70	0	Do.
35	393735104533901	74-04-22	19	600	100	21	3.6	66	--	120	12	118	39	16	2.0	<.10	--	<.10	--	238	66	0	--	3.5	--	8.0	--	--	--	--	Private
36	393749104581801	76-04-21	8.4	60	20	6.8	.9	52	1.3	143	0	117	15	1.8	1.6	--	.04	--	.01	159	21	0	84	5.0	185	8.3	13.0	9	390	0	USGS
37	393857105050601	76-05-05	8.0	60	20	29	3.3	180	2.7	191	0	157	290	12	1.6	--	.52	--	.01	623	86	0	81	8.4	720	7.9	13.0	0	70	0	Do.
38	393902104490901	60-07-07	15	110	0	10	1.7	52	3.2	145	--	119	19	2.0	1.6	.30	--	--	--	175	32	0	78	4.0	281	7.5	23.0	--	--	--	Do.

[1] U.S. Geological Survey.
[2] Reported as total iron.



MAP SHOWING AGGREGATE-SAND THICKNESS AND DEPTH TO BASE OF THE AQUIFER

MAP SHOWING WATER-QUALITY CHARACTERISTICS

Base from U.S. Geological Survey
Front Range Urban Corridor Maps:
Greater Denver Area and Colorado Springs—Castle Rock Area, 1972

Outcrop-subcrop area adapted from Chase and McConaghy (1972)

HYDROLOGY OF THE ARAPAHOE AQUIFER IN THE ENGLEWOOD—CASTLE ROCK AREA SOUTH OF DENVER, DENVER BASIN, COLORADO

By
Donald E. Hillier, Robert E. Brogden, and Paul A. Schneider, Jr.

1978

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