WATER-SUPPLY ASSESSMENT OF THE LARAMIE-FOX HILLS AQUIFER IN PARTS OF ADAMS, BOULDER, JEFFERSON, AND WELD COUNTIES, COLORADO

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CONTENTS

ILLUSTRATIONS

TABLES

METRIC CONVERSIONS

Inch-pound units used in this report may be converted to metric units by using the following conversion factors:

Multiply inch-pound unit	*By*	*To obtain metric unit*
foot	0.3048	meter
mile	1.609	kilometer
foot per mile	0.1894	meter per kilometer
acre	0.4047	hectare
acre-foot	0.001233	cubic hectometer
gallon per minute	0.06309	liter per second

NATIONAL GEODETIC VERTICAL DATUM OF 1929 (NGVD of 1929)

A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Sea Level Datum of 1929" or "mean sea level" in reports. Although the datum was derived from the average sea level over a period of many years at 26 tide stations along the Atlantic, Gulf of Mexico, and Pacific Coasts, it does not necessarily represent local mean sea level at any particular place.

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ABSTRACT

Ground water in the Laramie-Fox Hills aquifer is a potential source of supplemental municipal water supplies for the communities of Erie, Lafayette, Louisville, and Superior. The present water supplies for these communities are not always adequate to meet current demands. At the request of the U.S. Bureau of Reclamation, which is investigating and evaluating alternative sources of water for the communities, the U.S. Geological Survey made a water-supply assessment of the Laramie-Fox Hills aquifer.

Recharge to the aquifer is mostly in the western and southwestern parts of the study area. Ground-water movement is generally from the southwest to northeast. Ground-water discharge in the study area is primarily by pumping wells. Since 1961, this pumping has caused water-level declines of about 250 to 300 feet from Broomfield to east of Erie, Colo. Generally, water levels in other parts of the area have remained the same.

The aggregate sand and aquifer thickness determined from well logs ranges from 42 to 360 feet and the mean thickness is 229 feet. The volume of ground water in storage in the study area is about 5 million acre-feet. Reported yields from 93 wells ranged from 1 to 90 gallons per minute and averaged 22 gallons per minute. Well yields tended to be larger in the areas where aggregate sand thickness is the greatest.

The water changes from a sodium calcium bicarbonate type to a sodium calcium sulfate type as it moves through the aquifer away from the recharge areas. The maximum limit established by the U.S. Environmental Protection Agency for nitrite plus nitrate in public-water supplies was exceeded in water from three wells, the maximum limit for fluoride was exceeded in water from two wells, and the maximum limit for selenium was exceeded in water from three wells.

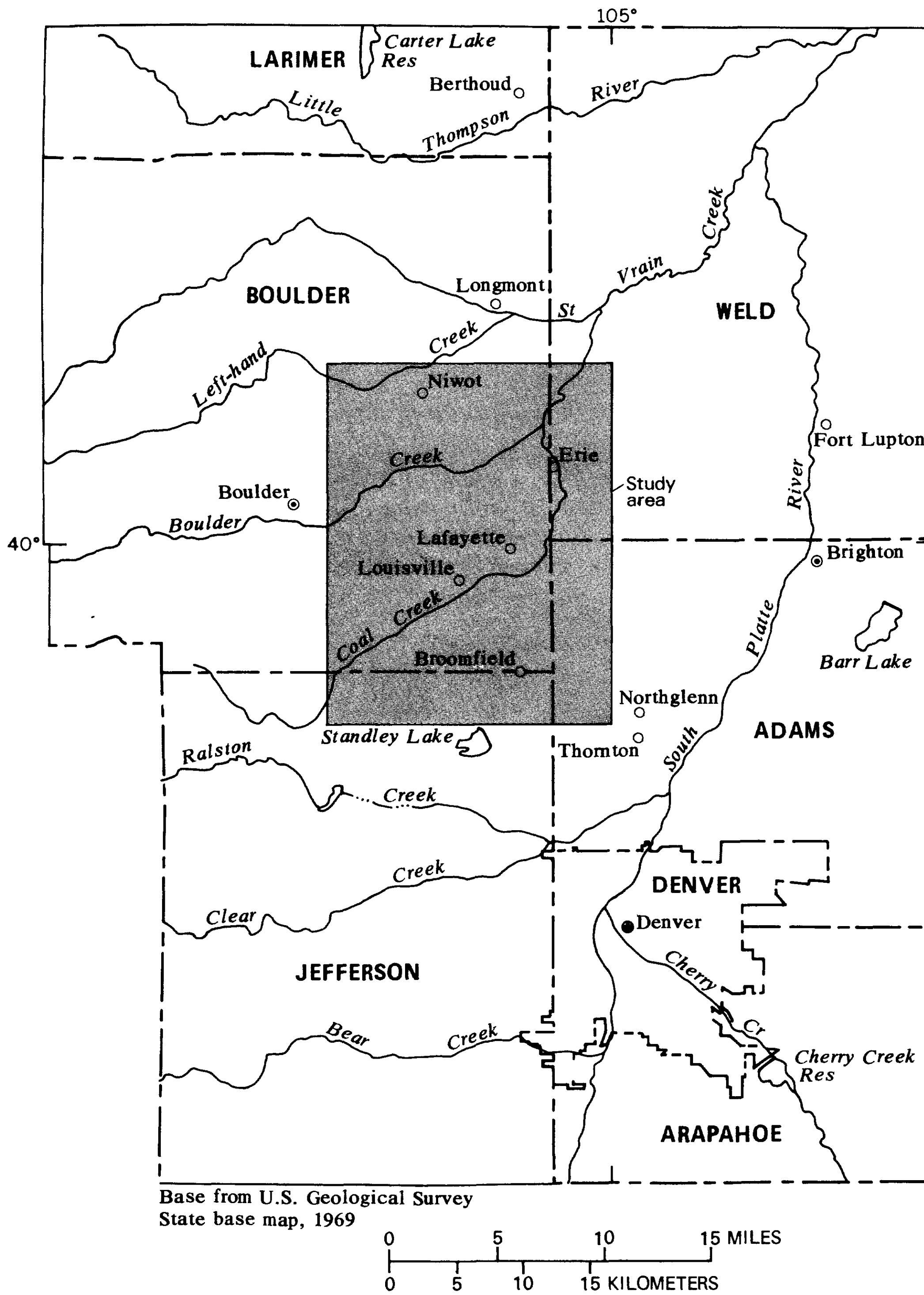

Figure 1.--Location of study area.

INTRODUCTION

The towns of Erie, Lafayette, Louisville, and Superior, 15 to 20 miles northwest of Denver, Colo., are in a rapidly expanding urban area called the Front Range Urban Corridor. Population increases have caused an increased need for water. The present water supplies for these communities are not always adequate to meet current demands, and restrictions on water use have been imposed. In March 1978, at the request of the U.S. Bureau of Reclamation, which is investigating and evaluating alternate sources of water for the communities, the U.S. Geological Survey began a study to determine the quantity and quality of water in the Laramie-Fox Hills aquifer so that this source could be evaluated as a possible supplemental supply of municipal water.

The present study was limited to the Laramie-Fox Hills aquifer within an area defined by the U.S. Geological Survey topographic maps for the Erie, Lafayette, Louisville, and Niwot 7½-minute quadrangles (fig. 1). The volume of water in and the yield of water from abandoned coal mines in the area are not included in this study because the mines generally are in one or more stratigraphic horizons above the top of the Laramie-Fox Hills aquifer. Cochran and Robinson (1973) reported, "Miners and the mining company's safety inspector report the mine (Crown) was considerably wetter during the irrigation season than during the rest of the year. They also stated that the mine intercepted a well that flowed at the surface. The casing was broken during mining and the water from the underlying sandstone caused flooding in the mine until the hole was plugged * * *."

Well records from the Colorado State Engineer's Office and data from files and published reports of the U.S. Geological Survey were used to construct the maps showing the potentiometric surfaces and the maps showing aquifer thickness and reported well yields. Reported data were not always verified. Unpublished water-quality data collected in the area were evaluated and incorporated into the maps showing chemical quality and specific conductance of water. These data also were used to compile the table summarizing the chemical quality of the water.

ACKNOWLEDGMENTS

Many people assisted in the collection and interpretation of data for this study. Their help is greatly appreciated. The landowners, who permitted access to the wells for measurements and water samples, were especially cooperative. Ms. Susan Schwartz, a summer employee hired through the Minority Participation in Earth Sciences program and a student at State University of New York at Binghamton, is due recognition for her assistance in tabulating, plotting, and analyzing the data used in this report.

LARAMIE-FOX HILLS AQUIFER

The Laramie-Fox Hills aquifer consists of the major sandstone beds at the base of the Laramie Formation and the underlying Fox Hills Sandstone of Late Cretaceous age. The aquifer is underlain by the Upper Cretaceous Pierre Shale, which includes the upper transition member. The thickness of the Pierre Shale is about 9,000 feet (Colton, 1978). The Pierre Shale is the underlying confining bed throughout the study area. Shales in the Laramie Formation above the aquifer form the upper confining bed in most of the study area. The outcrops of the aquifer are generally west of Louisville (Colton and Anderson, 1977; Machette, 1977; Spencer, 1961; and Trimble, 1975).

The extent and locations of the faults existing in the aquifer system have been discussed by Spencer (1961), Colton and Lowrie (1973), Trimble (1975), Colton and Anderson (1977), and Colton (1978).

Water-table conditions exist primarily in the outcrop-subcrop area along the western limit of the aquifer. Artesian conditions exist primarily throughout the rest of the study area, even where the aquifer is faulted to the surface, as evidenced by comparisons between water-level measurements made by the U.S. Geological Survey, and the top of the aquifer, as determined from drillers' logs.

Potentiometric Surface

The Laramie-Fox Hills aquifer in most of the study area is a confined aquifer, which means that the water in the aquifer is under pressure and will rise above the top of the aquifer in wells completed in the aquifer. In a few areas, the pressure is sufficient to cause the water in wells to rise above the land surface where the wells will flow if not shut in. The imaginary surface connecting water levels in wells tapping only the confined Laramie-Fox Hills aquifer defines the potentiometric surface.

The rate and direction of movement of water through an aquifer is seldom uniform because of changes in permeability, saturated thickness, and recharge-discharge relationships. Recharge and discharge to the aquifer affect the shape of the potentiometric surface more than any other factor. The direction of flow is generally perpendicular to the potentiometric contours and water moves from areas of recharge downgradient to points of discharge.

The potentiometric surface (pls. 1, 2) is highest in the southwestern part of the study area and lowest in the eastern and northeastern parts, indicating that ground-water movement, in general, is from the southwest to the northeast. The primary areas of recharge are in the western and southwestern parts of the area. The potentiometric surface under Rocky Flats has a gradient as steep as 200 feet per mile for about 3 miles east of the outcrop-subcrop area. The gradient and direction of ground-water movement indicate that the Laramie-Fox Hills aquifer is being recharged along the upturned edge of the aquifer as it subcrops beneath the saturated alluvium under Rocky Flats. Significant recharge also occurs on Davidson and Lake Mesas as a result of leakage from irrigation canals and from reservoirs cut into the underlying sandstones. Limited recharge occurs where saturated alluvium in stream valleys overlie the subcrop of the aquifer. Discharge from the aquifer is by pumpage and possibly by upward leakage into Boulder Creek downstream from the confluence with Coal Creek. Some leakage by gravity occurs from the aquifer to Boulder Creek valley upstream of the confluence of Coal Creek.

The mound in the potentiometric surface east of Lafayette is not the result of local recharge, but may be a remnant of the potentiometric surface that existed prior to extensive ground-water development in the area. The northeast-trending faults in the area may act as barriers to flow and may have minimized the effects of drawdown in this area. Another possible explanation for this mound is vertical leakage from overlying water-bearing formations along fault planes or directly down the well bore of corroded or improperly constructed wells.

Interpretations of the water-level data indicate that the general configuration of the potentiometric surface has persisted for more than 20 years (pls. 1, 2), but increased pumping since 1961 has slightly modified the configuration. As pumping increased, isolated cones of depression developed rapidly around the pumping centers. In the past, these cones remained relatively isolated because movement of water through the aquifer was impeded in some areas by impermeable fault zones. However, as pumpage continues to increase and the drawdown cones continue to expand, the shape of the potentiometric surface will be greatly modified in the next 20 years. This change in shape will be disclosed by a greater depth to the potentiometric surface below land surface, thereby increasing pumping lifts and costs. Increased pumpage also will decrease discharge to Boulder Creek valley. The depth to the potentiometric surface may be determined at any location by subtracting the altitude of the potentiometric surface shown on plate 2 from the altitude of the land surface.

Pumping has lowered the hydraulic head and decreased the altitude of the potentiometric surface by about 250 feet at Broomfield, Colo. The area of decline has become elongated and presently (1978) extends to near Erie, 8 miles to the northeast. The greatest declines in the potentiometric surface--about 300 feet--have occurred in this part of the area since the early 1960's. Outside of this area, little change in the potentiometric surface has occurred during the last 20 years.

Thickness

The composition of the Laramie-Fox Hills aquifer in the area is mostly sand. Therefore, the thickness of the aquifer shown on plate 3 and the aggregate sand thickness are virtually the same. This thickness was determined by examination of drillers' lithologic logs and electrical-resistivity logs for wells in the area. In parts of the study area, wells are constructed so close together that they cannot be plotted as individual data points on the map. Where these circumstances occurred, values were averaged and shown as one data point. Based on data from well logs, the thickness of the Laramie-Fox Hills aquifer ranges from 42 to 360 feet and the mean thickness is 229 feet. Reported thickness exceeds the values on those data points shown on plate 3 which are followed by a plus sign, because these wells are bottomed in sand.

No attempt was made to infer the effect of faulting on the thickness lines. On the downthrown side of some faults, thickening of the aquifer indicates movement contemporaneously with deposition (Louis Gaz, oral commun., 1978). This mechanism may be the cause of the greater than expected thickness of the aquifer in areas adjacent to faults.

Storage

The volume of water stored in the aquifer was calculated using aggregate sand thickness of the aquifer, specific yield, and area of the aquifer within the study area. The mean value of 229 feet was used for the aggregate sand thickness. Specific yield is the ratio of the volume of water which can be drained by gravity to the volume of rock drained, and is equal to porosity minus specific retention. The value for specific yield of 0.22, used in the calculation of volume of water in storage, was estimated using existing data from core samples previously analyzed by the U.S. Bureau of Reclamation and by the U.S. Geological Survey (McConaghy and others, 1964). Many of the samples were cored from outcrops, although some samples were obtained during well drilling. The area of the aquifer within the study area is 114,000 acres. Using these values, about 5 million acre-feet of water is stored in the Laramie-Fox Hills aquifer within the study area. Using the probable extremes of the individual variables, the limits of this estimate are a minimum of 2 million acre-feet and a maximum of 11 million acre-feet.

Well Yields

The yields of 93 wells completed in the Laramie-Fox Hills aquifer were obtained from data reported by well drillers to the Colorado State Engineer's Office and from data in reports published by the U.S. Geological Survey (Jenkins, 1961; McConaghy and others, 1964). The reported well yields shown on plate 4 range from 1 to 90 gallons per minute and average 22 gallons per minute.

The yield of a well depends on the pump capacity, well construction (table 1), and the hydrogeologic characteristics and conditions of the aquifer. One of the characteristics that contributes to the potential yield of a well is the aggregate sand thickness. The relationship between reported well yield and aggregate sand thickness determined by data from 35 wells in the study area (fig. 2) shows that as sand thickness increases the yield increases. The band shown in figure 2 represents plus or minus one standard error of estimate. The reported well yields may not represent the maximum yields that could be obtained from the aquifer principally because most of the wells were constructed for domestic use. Properly constructed wells equipped with larger capacity pumps may yield several times the amount of water normally obtained from domestic wells.

Chemical Quality of Water

The location of wells from which water samples were collected for chemical analysis or determination of specific conductance by the U.S. Geological Survey during 1975-78 (D. C. Hall, written commun., 1978) are shown on plates 5 and 6. The chemical analyses are listed in table 2. The water varied from a sodium calcium bicarbonate type to a sodium calcium sulfate type. The concentration of dissolved solids ranged from 171 to 2,910 milligrams per liter. Hardness ranged from 8 to 2,000 milligrams per liter.

Table 1.--*Construction details of selected wells shown on plate 3*

Well number	Total well depth (ft)	Casing diameter (in.)	Casing depth (ft)	Perforated casing interval (ft)	Perforated casing diameter (ft)	Reported yield (gal/min)	Reported water level, static (ft)	Reported water level, static (date)	Reported water level, pumping (ft)	Reported water level, pumping (date)	Water use	Date of construction
001	200	6-5/8 4-1/2	0-22 10-35	35-200	4-1/2	7	35	1-73	175	1-73	domestic	1-73
002	100	6 4	0-23 23-35	35-100	4	10	12	2-72	100	2-72	stock	2-72
003	[1]595	6	0-350	[2]350-595		20	220	6-64	345	6-64	domestic	6-64
005	310	6	0-124	[2]124-310		10	70	9-71	240	9-71	domestic	8-71
006	300	6-5/8 4	0-21 10-60	60-300	4	6	80	10-72	300	10-72	domestic	10-72
008	308	6-5/8	0-72	[2]72-308		20	45	1-73	240	1-73		1-73
009	154	6	0-154			3	50	11-60	145	11-60	domestic	11-60
010	[1]700	4-1/2	0-490	490-640 640-700	4-1/2 4	8	300	4-65	600	4-65	domestic	4-65
015	500	6	0-80	80-300	6	40	20	6-66	200	6-66	domestic	6-66
016	650	6-5/8 4-1/2	0-216 340-370 412-570 612-660	216-340 370-412 570-612	4-1/2	35	31	2-77	180	2-77	unused	2-77
017	[1]400	6	0-172	[2]172-400		30	0	8-64	210	8-64	stock	8-64
018	[1]390	5-5/8 4-3/8	0-185 185-390			15	60	9-72	310	9-72	irrigation	9-72
020	[1]200	6	0-21	[2]21-200		15	30	7-71	100	7-71	domestic	7-71
021	300	6-5/8	0-70	[2]70-300		60	90	4-67	120	4-67	stock	4-67
022	174	6	0-18	18-174	4	4	18	3-72	174	3-72	domestic	3-72
023	875	5	0-569	[2]569-875		25	80	3-66	181	3-66	public	3-66
024	500	6 5 4-1/2	0-40 40-110 110-305	[2]305-500		15	150	8-74	270	8-74	domestic	8-74
025	600	6-5/8	0-300	[2]300-600		30	35	6-65	170	6-65	sewer plant	6-65
026	475	6	0-263	[2]263-475		15	50	7-71	160	7-71	domestic	7-71
027	[1]400	10	0-110	110-400	8	79	54	4-66	254	4-66	commercial	3-66

Table 1.--*Construction details of selected wells shown on plate 3*--Continued

Well number	Total well depth (ft)	Casing diameter (in.)	Casing depth (ft)	Perforated casing interval (ft)	Perforated casing diameter (ft)	Reported yield (gal/min)	Reported water level, static (ft)	Reported water level, static (date)	Reported water level, pumping (ft)	Reported water level, pumping (date)	Water use	Date of con-struction
028	[1]365	8-5/8	0-76	[2]76-365		37-50	160	4-63	160	4-63	municipal	4-63
029	200	6	0-35	[2]35-200		2	18	5-67	200	5-67	domestic	5-67
030	780 [3]855	4-1/2	0-625	625-750	6	13	325	11-58	355	11-58	domestic	11-58
032	[1]600	6	0-315	[2]315-600		25	50	5-64	140	5-64	domestic	5-64
033	520	4-1/2	0-275	[2]275-520		8	175	1-61	375	1-61	domestic	1-61
036	[1]800	10 7-7/8 5-5/8	0-12 12-607	[2]607-800		15	22	3-59	300	3-59	domestic	3-59
037	535	6	0-299	[2]299-535		25	150	6-65	200	6-65	domestic	6-65
038	[1]487	6	0-300	[2]300-487		25	100	4-64	250	4-64	domestic	4-64
039	655	6	0-351	[2]351-655		25	180	11-68	185	11-68	domestic	11-68
043	[1]660	8-5/8	0-380	380-660	6-5/8	20	212	2-74	360	2-74		2-74
044	[1]600	6	0-405	[2]405-600		15	180	4-71	480	4-71	domestic	4-71
045	[1]700	6 4-1/2	0-21 21-359	359-700	4-1/2	15	250	6-67	450	6-67		6-67
047	615	5	0-334	[2]334-615		12	150	5-63	500	5-63	domestic	5-63
048	1,103	6-5/8 4-1/2	0-795 795-819	819-1,103	4-1/2	65	191	8-66				7-66
049	825	4-1/2	0-622	[2]622-825		12	200	3-68	500	3-68	domestic	3-68
050	1,022		0-101 101-760	760-1,022		16	273	6-58	300	6-58	commercial	6-58
051	[1]800	6	0-526	[2]526-800		25	220	7-65	335	7-65	domestic	7-65
064	650	10 7-3/4	0-31 31-650	400-650		20	150	9-58	325	9-58	domestic	9-58
068	239	5-5/8 4	0-73 55-193	193-239	4	30	181	5-60	200	5-60	domestic	5-60
071	832	8 6-5/8	0-23 23-700	700-832	6-5/8	15	260	10-58	300	10-58	domestic	10-58

Table 1.--*Construction details of selected wells shown on plate 3*--Continued

Well number	Total well depth (ft)	Casing diameter (in.)	Casing depth (ft)	Perforated casing interval (ft)	Perforated casing diameter (ft)	Reported yield (gal/min)	Reported water level, static (ft)	Reported water level, static (date)	Reported water level, pumping (ft)	Reported water level, pumping (date)	Water use	Date of construction
073	[1]575	8 4-1/2	0-22 22-334	[2]334-575		10	180	6-61	240	6-61	domestic	6-61
074	647	6 4-1/2	0-47 47-461	[2]461-647		10	160	1-58	220	1-58	domestic	1-58
076	[1]380	6	0-142	[2]142-380		20	110	3-67	290	3-67	domestic	3-67
081	400	6 4-1/2	0-25 20-260	[2]260-400		10	97	10-59	193	10-59	domestic	10-59
082	165	4-1/2	0-60	60-160	4-1/2	90	25	3-60	140	3-60	domestic	3-60
085	[1]255	7-1/2	0-51	[2]51-255		15	25	10-59	225	10-59	domestic	10-59
086	250	4-1/2	0-151	[2]151-250		15	40	12-59	200	12-59	domestic	12-59
091	[1]383	8-5/8	0-76	70-383	6-5/8	40	130	6-72	250	6-72		6-72
092	[1]200	6	0-35	[2]35-200		2	18	5-67	200	5-67	domestic	5-67
093	[1]427	6 4	0-28 28-210	[2]210-427		15	150	9-71	200	9-71		9-71
094	[1]210	6 4	0-20 10-60	60-210	4	15	15	6-71	165	6-71	domestic	6-71
095	200	6	0-42	[2]42-200		40	50	8-69	150	8-69	domestic	8-69
096	205	6-5/8	0-60	60-205	6-5/8	9	20	10-68	205	10-68	domestic	10-68
098	282	8	0-177	177-282	5-5/8	12	96	8-59	212	8-59	domestic	8-59
099	458	4-1/2	0-8 30-175	8-30 [2]175-458	4-1/2	10	18	9-58	22	9-58	domestic	9-58
102	580	4-1/2	0-323	[2]323-580		10	260	8-72	450	8-72	domestic	8-72
105	[1]325	7-7/8	0-44	44-325	5-5/8	12	200	7-58	325	7-58	domestic	7-58
106	254	6-5/8	0-74	74-254	4-1/2	12	38	8-72				8-72
107	1,099	7	0-732	732-1,093	7	75			445	3-58	commercial	3-58
108	[1]516	6	0-310	[2]310-516		25	80	7-69	300	7-69	domestic	7-69
109	150	6	0-21	[2]21-105		50	8	8-64	80	8-64	municipal	8-64

Table 1.--*Construction details of selected wells shown on plate 3*--Continued

Well number	Total well depth (ft)	Casing diameter (in.)	Casing depth (ft)	Perforated casing interval (ft)	Perforated casing diameter (ft)	Reported yield (gal/min)	Reported water level, static (ft)	Reported water level, static (date)	Reported water level, pumping (ft)	Reported water level, pumping (date)	Water use	Date of construction
110	155	6	0-21	[2]21-155		50	16	8-64	56	8-64	municipal	8-64
111	755	8-5/8 6-5/8	0-370 395-540	370-395 540-755	6-5/8	40	360	9-56			irrigation	9-56
112	[1]575	6	0-325	[2]325-575		20	200	10-64	280	10-64	domestic	10-64
113	[1]647	6 4-1/2	0-47 47-461	461-647		10	160	1-58	220	1-58	domestic	1-58
115	1,033	8-5/8	0-780	780-1,033	6-5/8	27	346	11-65	840	11-65	domestic	11-65
116	[1]565	5 4-1/2	0-87 87-301	[2]301-565		10	180	6-72	400	6-72	domestic	6-72
117	[1]665	6	0-424	[2]424-665		15	280	8-68	500	8-68	domestic	8-68
118	[1]865	5-5/8	0-730	[2]730-865		10	220	1-58	535	1-58	domestic	1-58
119	[1]925	4	0-835	835-925	4	10	350	6-71	550	6-71	domestic	6-71
120	1,075	6-5/8	0-775	769-1,075	4-1/8	38	190	9-65	290	9-65	domestic	9-65
121	1,100	4-1/2	0-948	948-1,100	4-1/2	29	160	7-58	224	7-58	domestic	7-58
123	498	4	0-280	[2]280-498		15	85	6-62	85	6-62	domestic	6-62
124	614	6	0-373	[2]373-614		20	120	3-71	170	3-71	domestic	3-71
126	548	4-1/2	0-360	[2]360-548		10	200	6-62	350	6-62	domestic	6-62
127	709	6-5/8	0-372	372-709	4-1/2	32			314	8-62	domestic	8-62
128	[1]600	6	0-350	[2]350-600		15	245	3-64	345	3-64	domestic	3-64
129	575	6	0-310	310-575	6	20	250	5-70	325	5-70	domestic	5-70
130	620	4-1/2	0-400	[2]400-625		10	270	4-68	270	4-68	domestic	4-68
133	[1]960	6-5/8	0-660	660-960	6-5/8	30	317	11-65	350	11-65	municipal	11-65
134	580	4-1/2	0-323	[2]323-580		10	260	8-72	450	8-72		8-72
135	390	6	0-240	[2]240-390		15	140	7-61	350	7-61	domestic	7-61

Table 1.--*Construction details of selected wells shown on plate 3*--Continued

Well number	Total well depth (ft)	Casing diameter (in.)	Casing depth (ft)	Perforated casing interval (ft)	Perforated casing diameter (ft)	Reported yield (gal/min)	Reported water level, static (ft)	Reported water level, static (date)	Reported water level, pumping (ft)	Reported water level, pumping (date)	Water use	Date of construction
136	[1]550	6-1/2	0-300	[2]300-550		15	110	7-71	360	7-71	domestic	7-71
142	93	4-1/2	0-20	20-90	4-1/2	1	20	11-60	93	11-60	irrigation	11-60
145	450	4-1/2	0-322	[2]322-450		7	225	9-61	350	9-61	domestic	9-61
147	610	4-1/2	0-410	[2]410-610		15	225	7-73	380	7-73		7-73
151	185	6	0-22	22-185	4-1/2	30	6	7-68	80	7-68	domestic	7-68
152	175	6	0-22	[2]22-175		10	260	8-72	450	8-72	domestic	8-72
153	[1]180	6	0-21	[2]21-180		14	20	5-64	160	5-64	domestic	5-64
154	1,099	7	0-732	[2]732-1,093		75			445	3-58	commercial	5-58
155	1,103										domestic	8-66
156	480	5 4-1/2	0-22 22-330	[2]330-480		10	140	6-63	270	6-63	domestic	6-63
157	500	6	0-80	80-300 300-500	6	40	20	6-66	200	6-66	domestic	6-66
158	1,201	6									domestic	2-57
159	545	8	0-189	[2]189-545		14	20	5-64	160	5-64	domestic	5-64
160	585										commercial	7-54

[1]Well does not completely penetrate aquifer.
[2]Open hole.
[3]Plug.

Table 2.--*Summary of chemical analyses*

[μmho/cm at 25°C=micromho per centimeter at 25° Celsius, mg/L=milligram per liter, μg/L=microgram per liter]

Local identifier	Date (Y-M-D)	Specific conductance (μmho/cm at 25°C)	pH	Water temperature (°C)	Hardness (mg/L)	Noncarbonate hardness (mg/L)	Dissolved calcium (Ca) (mg/L)	Dissolved magnesium (Mg) (mg/L)	Dissolved sodium (Na) (mg/L)	Percent sodium	Sodium adsorption ratio	Dissolved potassium (K) (mg/L)	Bicarbonate (HCO_3) (mg/L)
Maximum limit[1]--------		-----	-------	----	-----	-----	-----	-----	-----	--	----	---	---
Recommended limit[2]----		-----	6.5-8.5	----	-----	-----	-----	-----	-----	--	----	---	---
SB00106821CBC--	78-03-15	2,200	8.4	13.0	21	0	5.9	1.6	590	98	56	3.2	560
SB00106907AAA--	76-02-05	1,300	-------	----	630	250	100	93	47	14	.8	3.3	442
SB00106913BCA--	76-07-22	2,800	-------	15.0	960	-----	220	99	420	49	5.9	4.0	772
SB00106920AAC--	75-11-24	1,400	-------	----	640	340	190	39	100	25	1.7	1.9	358
SB00106920ABC--	76-10-05	1,420	-------	13.5	670	340	140	77	80	21	1.3	1.9	399
SB00106931ABB--	75-12-02	3,500	-------	----	2,000	1,400	320	280	230	20	2.3	3.2	642
SB00106934DAD--	75-12-17	1,350	-------	----	25	0	6.0	2.3	340	97	30	1.7	369
SC00106922ADC--	75-12-13	790	-------	----	8	0	2.0	.7	170	98	26	1.2	392
SC00107001AAB--	76-03-23	1,050	-------	14.0	460	180	98	52	49	19	1.0	2.7	346
SC00107012AAD--	76-03-30	790	-------	----	260	0	57	29	76	38	2.0	2.9	385
SC00107012ACC--	76-03-26	500	-------	----	220	0	54	20	21	17	.6	1.6	273
SC00107013CDA--	76-02-04	270	-------	----	140	24	45	7.0	7.7	11	.3	.7	143
SC00107015CAA--	76-03-26	800	-------	----	140	0	25	18	130	67	4.8	3.3	369
SC00107021BDA--	76-07-21	690	-------	----	300	57	85	22	41	23	1.0	2.2	300

Table 2.--*Summary of chemical analyses*--Continued

Local identifier	Date (Y-M-D)	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)	Dissolved solids (sum of constituents) (mg/L)	Dissolved nitrite (N) (mg/L)	Dissolved nitrite plus nitrate (N) (mg/L)	Dissolved orthophosphorus (P) (mg/L)	Dissolved boron (B) (µg/L)	Dissolved iron (Fe) (µg/L)	Dissolved manganese (Mn) (µg/L)	Dissolved selenium (Se) (µg/L)
Maximum limit[1]--------		--	---	-----	-----	[3]1.8-2.2	-----	----	10	----	-----	---	---	10
Recommended limit[2]----		--	---	250	250	--------	500	----	-----	----	-----	300	50	--
SB00106821CBC--	78-03-15	8	470	720	42	2.2	1,660	----	0.77	0.11	520	130	20	0
SB00106907AAA--	76-02-05	12	383	330	8.2	2.4	836	0.00	.15	.01	220	10	50	0
SB00106913BCA--	76-07-22	--	---	1,100	29	3.3	>500	.00	8.1	.09	1,600	140	10	14
SB00106920AAC--	75-11-24	--	294	450	21	.3	1,050	----	12	.01	1,900	30	10	2
SB00106920ABC--	76-10-05	--	327	460	20	--------	>500	----	4.8	----	-----	---	---	--
SB00106931ABB--	75-12-02	--	527	1,700	40	2.0	2,910	----	.22	.02	340	550	150	18
SB00106934DAD--	75-12-17	--	303	390	21	1.1	953	.01	.03	.04	240	100	20	0
SC00106922ADC--	75-12-13	--	322	11	31	.9	420	----	.17	.01	120	40	0	0
SC00107001AAB--	76-03-23	--	284	200	33	.5	663	.05	9.5	.00	60	20	40	15
SC00107012AAD--	76-03-30	--	316	63	11	.9	496	.01	11	.00	90	0	10	2
SC00107012ACC--	76-03-26	--	224	45	3.5	.5	302	.01	.09	.00	20	30	100	0
SC00107013CDA--	76-02-04	--	117	20	3.6	.4	171	.00	.74	.00	20	0	0	0
SC00107015CAA--	76-03-26	--	303	110	2.9	.9	496	.01	.91	.01	110	0	0	0
SC00107021BDA--	76-07-21	--	246	46	38	.3	457	.00	11	.04	70	40	10	4

[1]Established by U.S. Environmental Protection Agency (1976).
[2]Established by U.S. Environmental Protection Agency (1977).
[3]Range in mg/L determined by annual average of maximum daily air temperature for the location of the water system.

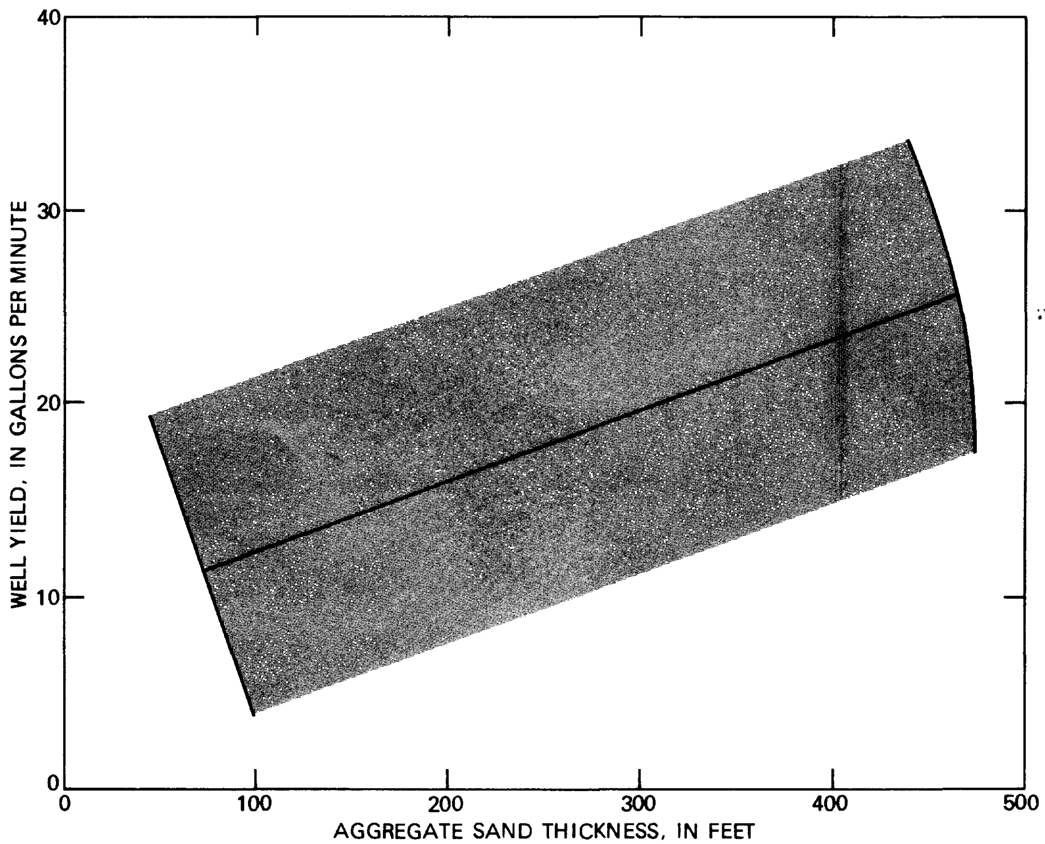

Figure 2.--Relation between well yield and aggregate sand thickness.

Interpretation of the data indicates that as the water in the aquifer moves downgradient and away from the recharge area it changes from a sodium calcium bicarbonate type to a sodium calcium sulfate type. This change in water type is a result of ion exchange as the water moves through the coal and carbonaceous clay and shale existing in the formation. The diversity of water type across the study area is controlled by the amount and type of water recharged to the aquifer, vertical leakage from overlying or underlying water-bearing formations, and residence time of the water in the formation. Other factors which may contribute to the deterioration of water quality are improper well construction and deterioration of casing, which would allow more mineralized water from other water-bearing zones to enter the well.

Nitrite plus nitrate concentrations in water from three wells, fluoride concentrations in water from two wells, and selenium concentrations in water from three wells exceeded the maximum limits for public-water supplies established by the U.S. Environmental Protection Agency (1976). Dissolved-solids concentrations in water from eight wells, the iron concentration in water from one well, manganese concentrations in water from two wells, and sulfate concentrations in water from seven wells exceeded the recommended limits for public-water supplies established by the U.S. Environmental Protection Agency (1977). At least one constituent in water from 12 of the 14 wells exceeded either the maximum or recommended limits.

ADDITIONAL DATA REQUIREMENTS

Examination and interpretation of the available data have indicated that there are some data deficiencies that need to be eliminated if a complete definition and understanding of the hydrologic system of the area is to be made. Additional well data, such as location, depth, water level, and yield, are needed in selected parts of the study area. Water-level data are needed particularly across the northern and southern parts of the study area to better define the potentiometric surface. Data to determine the relationship between faulting and the potentiometric surface are needed.

Aquifer tests are needed throughout the study area to refine the estimates of specific yield used in calculating the volume of water in storage. These tests and data also would aid in making better estimates of potential well yield.

Additional water-quality data would contribute to a more complete description of the water quality of the area. It also would provide a basis for a better understanding of the changes in water quality that could occur and the factors that control these changes.

SUMMARY

Water in the Laramie-Fox Hills aquifer is a potential source that could be used to supplement the existing municipal water supplies of the communities of Erie, Lafayette, Louisville, and Superior. The altitude of the potentiometric surface has declined as much as 300 feet in parts of the area in and adjacent to the major centers of pumping, but the data also indicate little change in water levels in the area generally west and north of Coal Creek. The increase in construction of wells and the associated increase in pumping over the last 20 years has slightly modified the shape of the potentiometric surface. The shape and modification of the potentiometric surface also is affected by faulting of the aquifer in the area. In the next 20 years increased pumpage probably will cause a greater change in the potentiometric surface than has occurred during the last 20 years. These changes will include greater depths to the potentiometric surface, an increase in pumping lifts and costs, and decreased discharge to Boulder Creek valley.

Aggregate sand thickness of the aquifer determined from well logs ranges from 42 to 360 feet and the mean thickness is 229 feet. About 5 million acre-feet of water is in storage in the aquifer.

Reported yields from 93 wells ranged from 1 to 90 gallons per minute. The average yield was 22 gallons per minute. A plot of well yield versus aggregate sand thickness indicates that yields tended to be larger from areas of greater aggregate sand thickness.

Water moving through the aquifer comes into contact with coal and other beds of carbonaceous material which causes the water to change from a sodium calcium bicarbonate type to a sodium calcium sulfate type. Analyses of water samples collected from 14 wells indicate that there is a change in water quality down-gradient from the recharge areas. Nitrite plus nitrate concentrations in water from three wells, fluoride concentrations in water from two wells, and selenium concentrations in water from three wells exceeded the maximum limits for public-water supplies established by the U.S. Environmental Protection Agency (1976).

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