

EVALUATION OF GROUND-WATER-LEVEL CHANGES NEAR GILLETTE, NORTHEASTERN WYOMING

INTRODUCTION

This study, done in cooperation with the Wyoming State Engineer, investigates the geology in an area of about 220 mi² in northeastern Wyoming that includes the urbanized region near Gillette (fig. 1). Gillette is the county seat of Campbell County and the principal trading center in the northeastern part of the State.

Energy development in northeastern Wyoming caused dramatic population growth in Campbell County since about 1960 (fig. 2). The population in the study area is assumed to follow a trend similar to that shown in figure 2 because much of the population growth in Campbell County occurred in the vicinity of Gillette. The population of Gillette increased from 3,150 (Littleton, 1950, p. 1) in 1950 to about 15,000 in 1985.

Ground-water development in the study area includes wells for the Gillette public-water supply, for separate water supplies developed for many subdivisions, for waterflooding in oil fields, and for facilities at nearby surface mines. Also, there are many stock and domestic wells near Gillette.

Local water users are concerned that pumping may be causing water levels to decline, and some users are concerned that pumping of the deep wells may affect the water levels in the shallower aquifers. Methods used to verify declines and, if declines are occurring, the areal extent of declines and location of the stratigraphic zones in which the declines are occurring.

Purpose and Scope

The purpose of this report is to present concepts of ground-water flow in the Powder River structural basin in northeastern Wyoming based on investigations of the effects of pumping. Evaluation of water-level changes in the Fort Union Formation of Tertiary age is emphasized because much of the recent pumping activity has been from wells completed in the Fort Union. There were insufficient data to estimate transmissivity from pumpage and draw-down data.

Well records, driller's lithologic logs, and geophysical logs were examined to determine the well-completion method and the water-yielding zones. Wells were inventoried, and water levels were measured periodically in wells that had air lines installed.

The records of about 100 wells near Gillette had data to define well completion, water level, and the lithology drilled. These wells were selected to be representative of all the wells completed in the principal aquifers (fig. 3).

Driller's lithologic logs and the depths of perforated intervals for the water wells were compared with geophysical logs of oil-test holes drilled in the area in order to determine which geologic formation yielded water to each well. The formations were differentiated using formation tops picked on geophysical logs by the Wyoming State Engineer (U.S. Geological Survey, commun., 1985). Water levels are grouped according to total depth and depths of the perforated interval for identification purposes. In this report, the groups are designated as wells in the Wasatch Formation, upper and lower parts of the Fort Union Formation, and Lance Formation and Fox Hills Sandstone; however, perforated intervals in some wells were open to more than one formation.

Previous Investigations

Lowry, Wilson, and others (1986, p. 201) list more than 350 references that include geology and hydrology in the Powder River structural basin. In addition, records of wells, pumpage data, and some water-level data are filed with the Wyoming State Engineer's Office.

Several water-level contour maps have been published. The contour map prepared by King (1974) probably is representative of the altitude of the first water level that might be encountered when drilling a well in the study area. Annual reports published by the Gillette Area Groundwater Monitoring Organization (GAGMO) from 1983 to 1985 include potentiometric-surface maps and water-level-change maps for the Wasatch Formation and the underlying Wyodak coal bed in the Tongue River Member of the Fort Union Formation at most coal-mine sites. In addition, well location, aquifers in which wells are completed, and water levels are reported annually by GAGMO. These water-level data are for wells completed in shallow aquifers, most of which are less than 500 ft deep. Hotchkiss and Levings (1986, figs. 8-12) and Daddow (1986) show contour maps of water levels for wells completed in deeper formations.

Well-Numbering System

Wells cited in this report are numbered by a method based on the U.S. Bureau of Land Management system of land subdivision in Wyoming (fig. 4). The first number indicates the township, the second the range, and the third the section in which the well is located. The capital or lowercase letters following the section number indicate the location of the well in the section. The first letter denotes the quarter section, the second letter the quarter-quarter section, and the third letter the quarter-quarter-quarter section (10-acre tract). The subdivisions of a section are lettered A, B, C, and D in a counterclockwise direction, starting in the northeast quarter. If more than one well is listed in a 10-acre tract, consecutive numbers starting with 1 follow the letters of the well number. If a section does not measure 160 acres, it is treated as a full section with the southeast section corner serving as the reference point for the subdivision of the section.

Acknowledgments

The author thanks many residents who provided information about wells and permitted U.S. Geological Survey personnel to measure water levels in their wells. The management personnel of several Gillette subdivisions provided access to their wells and water levels. The City of Gillette Water Department and Mr. Gerald Dickinson gave permission to install digital water-level recorders on wells.

Geology

The principal aquifers in the study area, in descending order, are the Wasatch and Fort Union Formations of Tertiary age, and the Lance Formation and the Fox Hills Sandstone of Cretaceous age. The alluvium is a generally thin aquifer and not extensive in the study area; wells completed in the alluvium were not included in this study. Aquifers deeper than the Fox Hills Sandstone are not utilized extensively in the study area. Gillette has municipal wells completed in the Madison Limestone of Mississippian age, but those wells are located about 30 mi east of Gillette and are outside the study area.

There is some disagreement among investigators as to the exact location of the contact between the Wasatch and Fort Union Formations. Generally, the boundary is considered to be at or somewhat above the top of the Wyodak-Anderson coal bed (Keefer and Hadley, 1976, p. 4). Law (1976, p. 271) considered the top of the Wyodak coal bed (Wyodak-Anderson) as the contact between the Wasatch and Fort Union Formations. This contact is used in this study.

The principal effort in this study is to determine which formations are used as the main source of water and to interpret the effects of pumping on water levels in those formations. Although the Wasatch Formation is the shallowest aquifer, the Fort Union Formation is most likely to be developed for future ground-water supplies because better quality water is obtained from this formation.

The general relation between the several formations as sources of ground water can be illustrated by the source of water pumped for Gillette municipal use. Municipal pumpage reported to the Wyoming State Engineer by the city of Gillette (fig. 5) consists of pumpage from wells completed in the Wasatch and Fort Union Formations, the Fox Hills Sandstone, and the Madison Limestone. Water from the Wasatch Formation was not pumped after water from the Madison Limestone became available in 1982.

Wasatch Formation

The Wasatch Formation is exposed at the surface in most of the study area and consists of lenticular fine- to coarse-grained sandstone and interbedded shale and coal (Hodson and others, 1973, sheet 3). In the Gillette area, the average thickness of the formation is about 490 ft. Many stock and domestic wells are completed in the Wasatch because ground water is available from relatively shallow depths. Most people consider the quality of this water to be inferior to water obtained from deeper formations.

Fort Union Formation

The Fort Union Formation consists of three members which are, from the youngest to oldest, the Tongue River, Lebo Shale, and Tilloo Members (Law, 1976, p. 221). However, the Tongue River Member is absent within the boundary of this study (fig. 6) (Denson, Macke, and Schumann, unpublished mapping). Although the top of the Fort Union is shown on the geophysical log in figure 6, the thickness of the Wyodak-Anderson coal bed, in this study the top of the Fort Union is assumed to be the top of the Wyodak-Anderson coal bed. The average thickness of the Fort Union Formation is about 1,800 ft. The stratigraphy of the Fort Union Formation is complex as indicated by the electric log in figure 6. Because of the lateral discontinuity of sandstone lenses, it is difficult to correlate the lithology between wells, and it often is difficult to determine if nearby wells are completed in the same sequence of sandstone lenses that should permit good hydraulic connection between wells. Hodson and others (1973, sheet 3) describe the Fort Union Formation as fine-grained sandstone, and interbedded shale, and coal.

Electric logs in combination with gamma-ray logs and driller's lithologic logs provide the best data for selecting intervals to perforate or screen. Geophysical logs are not always available to define the best aquifer zones, and many wells are perforated on the basis of only the driller's knowledge about the lithology gained while drilling the hole.

It is difficult to identify any particular zone or sometimes even the formation in which the water wells are completed. The formations in the study area are the Wasatch Formation, Lance Formation and Fox Hills Sandstone; however, perforated intervals in some wells were open to more than one formation.

Lance Formation and Fox Hills Sandstone

The Lance Formation and the Fox Hills Sandstone are assumed to be hydraulically connected and to respond as one aquifer. The combined thickness of the Lance and Fox Hills averages about 1,600 ft in the study area. The Lance Formation is fine- to medium-grained sandstone interbedded with sandy shale and claystone beds (Hodson and others, 1973, sheet 3). Some workers divide the Lance into upper and lower members (Norman M. Denson, U.S. Geological Survey, oral commun., 1986). The geophysical log in figure 6 illustrates the interbedded nature of the Lance Formation, making it difficult to correlate particular beds from one place to another. The Fox Hills Sandstone is predominantly fine- to medium-grained sandstone containing thin beds of sandy shale (fig. 6). The upper part that is equivalent to the Colgate Member of the Fox Hills Sandstone in Montana is differentiated from the lower member at some locations. The Pierre Shale of Cretaceous age underlies the Fox Hills Sandstone. The contact between the Fox Hills and the Pierre is one of the most easily identified features on electric logs throughout the region. Wells are completed in either the Lance or the Fox Hills, or both, and in this report are referred to as wells in the Lance Formation and Fox Hills Sandstone.

Wells in the upper part of the Fort Union Formation

The water levels in wells in the upper part of the Fort Union Formation in 1985 were substantially lower than when the wells were drilled (fig. 9). The water levels measured during 1975 in 17 wells range from about 39 to about 455 ft lower than the initial reported water level. All but 2 of the 17 wells are used as production wells; therefore, some of the water levels measured during 1985 were lower because of residual drawdown resulting from pumping. It was usually not known how recently the well was pumped prior to the measurement.

To help define the water-level changes in the upper part of the Fort Union Formation, digital water-level recorders were installed on two wells in the upper part of the Fort Union. At well 50-72-208A, a digital water-level recorder was installed May 7, 1985. The water-level decline from May through October in this unused well (fig. 9) probably was caused by pumping in the upper part of the Fort Union. A water-level measurement made in December 1985 indicated that the water level had stabilized, although there was no indication of water-level recovery in the observation well. At well 50-72-208B, the digital water-level recorder was installed in December 1985 (hydrograph not shown). Not enough data have been collected to establish a trend of the water level, although water-level measurements made from October 1985 to January 1986 indicate that the water level in this well has risen 17 ft during this short period. The recorder will be used in this study as more data are needed to help explain the water-level rise.

Wells in the lower part of the Fort Union Formation

Water-level changes in the lower part of the Fort Union Formation are not well documented because the water levels reported at similar depths illustrate the effect of pumping other wells also completed in the Wasatch (fig. 8). The hydrographs for well 50-72-208B, in the Wasatch Formation, which is near well 50-72-218A, in the Wasatch Formation, which was drilled before and during the population growth at Gillette. Water levels were measured for 25 years (1911-74) in well 50-72-208B before it was destroyed in 1974 (Ringer, 1973 and 1974, and Ballance and Freudenthal, 1975). The hydrograph (fig. 8) shows the water-level increase after 1961. The declining water level from 1965 through 1974 probably accounts for the rising water level. If pumpage of water from the Wasatch Formation probably accounts for the rising water level. The decline of water level in well 50-72-218A probably will rise to a relatively high level similar to that measured in well 50-72-208B prior to 1961.

Comparison between the hydrographs for wells 50-72-208D and 50-72-218A and annual precipitation (fig. 8) indicates that water levels in the Wasatch Formation may be partially affected by long-term changes in annual precipitation. It is unlikely that water-level changes resulting from differing recharge and precipitation could be identified in the deeper aquifers that are below the Wasatch Formation because low vertical permeability would restrict downward movement of recharge.

Wells in the Lance Formation and Fox Hills Sandstone

The principal aquifers in the study area, in descending order, are the Wasatch and Fort Union Formations of Tertiary age, and the Lance Formation and the Fox Hills Sandstone of Cretaceous age. The alluvium is a generally thin aquifer and not extensive in the study area; wells completed in the alluvium were not included in this study. Aquifers deeper than the Fox Hills Sandstone are not utilized extensively in the study area. Gillette has municipal wells completed in the Madison Limestone of Mississippian age, but those wells are located about 30 mi east of Gillette and are outside the study area.

Most of the well data were obtained from records on file at the Wyoming State Engineer's Office. The records indicate that most wells have casing cemented from land surface to the bottom of the well. The casing is perforated at the Wyodak-Anderson coal bed (Keefer and Hadley, 1976, p. 4). Law (1976, p. 271) considered the top of the Wyodak coal bed (Wyodak-Anderson) as the contact between the Wasatch and Fort Union Formations. This contact is used in this study.

The variation in hydraulic head is illustrated in the graph of initial water-level altitudes and the well-bottom altitudes for wells in the upper and lower parts of the Fort Union and wells in the Lance Formation and Fox Hills Sandstone (fig. 7). In those wells where perforated intervals are known, most perforations are in the bottom 100 feet, therefore, the altitude of the well bottom should be a reasonable representation of the altitude at which the head was measured. The distribution of data points shows poor correlation of hydraulic head with depth although there may be a slight trend of decreasing hydraulic head with depth for wells in the lower part of the Fort Union and Lance and Fox Hills. Decreasing hydraulic head with depth has also been noted by other investigators (Ground-Water Subgroup of Water Work Group Northern Great Plains Resource Program, 1974, p. 38) suggesting that vertical ground-water flow is downward and that the deeper aquifers potentially can be recharged from overlying beds. However, because of the interbedding of sandstone, shale, and coal, the discontinuous sandstone beds, and the wide range of hydraulic heads, vertical hydraulic connection probably is poor. It is possible that pumping water from the lower part of the Fort Union Formation and below may affect water levels in wells in the upper part of the Fort Union, but the effects on water levels of pumping water from wells completed in the upper part of the Fort Union will mask the effects of pumping from the lower part.

Wells in the Wasatch Formation

The hydrographs for two observation wells completed in the Wasatch Formation at similar depths illustrate the effect of pumping other wells also completed in the Wasatch (fig. 8). The hydrograph for well 50-72-208B, in the Wasatch Formation, which is near well 50-72-218A, in the Wasatch Formation, which was drilled before and during the population growth at Gillette. Water levels were measured for 25 years (1911-74) in well 50-72-208B before it was destroyed in 1974 (Ringer, 1973 and 1974, and Ballance and Freudenthal, 1975). The hydrograph (fig. 8) shows the water-level increase after 1961. The declining water level from 1965 through 1974 probably accounts for the rising water level. If pumpage of water from the Wasatch Formation probably accounts for the rising water level. The decline of water level in well 50-72-218A probably will rise to a relatively high level similar to that measured in well 50-72-208B prior to 1961.

Wells in the Lance Formation and Fox Hills Sandstone

Water-level changes were analyzed for eight wells completed in either the Lance Formation or the Fox Hills Sandstone, or in both formations. One well probably yields most of its water from the Lance, and one well is completed in both the Lance and the Fox Hills. The other six wells were reported to be yielding water from the Fox Hills, but records are not available to verify this. No water-level data are available for wells in the Wasatch from 1975-82.

Well 49-70-318B, completed in the Lance and Fox Hills, is used as an observation well to monitor water-level changes. A digital water-level recorder has been operated by the Wyoming State Engineer's Office since the well since September 1983. The hydrograph (fig. 10) shows that the water level has declined about 9 ft from the initial water level in 1983 to December 1985. The well was drilled in 1981, the initial water level was reported to be at 490 ft below land surface. The water-level decline probably is the result of pumpage for industrial use because there are 14 oil-field waterflooding operations withdrawing water from the Fox Hills Sandstone within a radius of about 10 mi of the observation well.

Water-level data were too few to map a realistic potentiometric surface for the Lance Formation and the Fox Hills Sandstone within the study area. Initial water levels reported at the eight wells in the Lance and Fox Hills used in this study indicate that the gradient of the potentiometric surface is northwesterly, which is similar to the direction of flow indicated by the regional potentiometric surface shown by Henderson (1985, fig. 33, p. C 44) for the Lance and Fox Hills.

Summary and Conclusions

Ground-water-level changes were evaluated in an area of about 220 mi² in northeastern Wyoming, including the urbanized region near Gillette, where ground-water development is most concentrated. Local water users are concerned that water levels are declining.

CONVERSION FACTORS AND VERTICAL DATUM

| Multiply | By | To obtain |
|--|-----------|------------------------|
| Foot (ft) | 0.3048 | meter |
| mile (mi) | 1.609 | kilometer |
| acre | 4,047 | square meter |
| square mile (mi ²) | 2,590 | square kilometer |
| cubic foot per second (ft ³ /s) | 0.02832 | cubic meter per second |
| Foot squared per day (ft ² /d) | 0.09290 | meter squared per day |
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Water-level data from 1949 to 1985 from a well completed in the Wasatch Formation indicate that the water level was relatively stable prior to 1961 when the population of the Gillette area started to increase. From about 1965 through 1974, the water level declined about 9 ft. No water-level data are available for wells completed in the Wasatch from 1975-82. The water level in another well completed in the Wasatch Formation and equipped with a digital water-level recorder has been rising since 1983, probably because Gillette stopped pumping water from the Wasatch Formation for municipal use after 1981.

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Some large differences in hydraulic head may be explainable. At nearby well 50-72-303B, the initial water level altitude was 270 ft when the well was drilled in 1979 and was 4,276 ft on August 15, 1985. When measured in 1985, gas was escaping from the water surface, and the water level seemed to fluctuate about 10 ft because of much bubbling action caused by the gas release. Comparison of the driller's lithologic log and geophysical logs of nearby wells indicates that the uppermost perforations in well 50-72-303B are probably in the Lance Formation. The water level could account for the relatively high initial water level as a result of partial gas lift. Dissipation of gas could account for part of the water-level decline since the well was drilled. Because the gas is still escaping and contributing to the hydraulic head in the well, the water level would most likely decline below its present level if the gas was sealed off.

Examination of the 17 hydrographs for wells completed in the upper part of the Fort Union Formation (see fig. 9) indicates that the average water-level decline in these wells is about 120 ft and has occurred from about 1972 to 1985; however, the average length of pumpage has been only 10 years. Very few water-level data are available from the time the wells were completed until 1985, and it is not possible to determine if the water-level decline has changed. More data are needed to determine the current trend of water-level changes.

A regional flow pattern of ground-water movement could not be determined for the upper part of the Fort Union Formation in the study area. The initial water levels reported at the time the wells were drilled were used as control for a potentiometric surface. An attempt to construct a potentiometric surface for the study area, using the initial water levels reported, resulted in a very unrealistic pattern of ground-water movement within the study area. The water levels reported at the time the wells were drilled are used as control for a potentiometric surface, but the effects on water levels of pumping water from wells completed in the upper part of the Fort Union will mask the effects of pumping from the lower part.

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