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GEOLOGICAL SURVEY

EFFECT OF PUMPAGE ON GROUND-WATER LEVELS AS MODELED IN LARAMIE COUNTY, WYOMING

By Marvin A. Crist

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UNITED STATES DEPARTMENT OF THE INTERIOR

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METRIC CONVERSION AND VERTICAL DATUM

For those readers interested in using the metric system, the following table may be used to convert the inch-pound units of measurement used in this report to metric units:

Multiply	By	To obtain
acre	4.047×10^{-3}	square meter
acre-foot (acre-ft)	1.233×10^{-3}	cubic meter
cubic foot per second (ft^3/s)	2.832×10^{-2}	cubic meter per second
cubic foot per second per square foot [$(ft^3/s)/ft^2$] After unit cancellation = foot per second (ft/s).	3.048×10^{-1}	cubic meter per second per square meter After unit cancellation = meter per second
foot (ft)	3.048×10^{-1}	meter
foot per day (ft/d)	3.048×10^{-1}	meter per day
gallon per minute (gal/min)	6.309×10^{-5}	cubic meter per second
	6.309×10^{-2}	liter per second
inch (in.)	2.540×10^{-1}	millimeter
mile (mi)	1.609	kilometer
square foot (ft^2)	9.290×10^{-2}	square meter
square mile (mi^2)	2.590	square kilometer

National Geodetic Vertical Datum of 1929 (NGVD of 1929) is 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.

EFFECT OF PUMPAGE ON GROUND-WATER LEVELS AS MODELED IN LARAMIE COUNTY, WYOMING

By Marvin A. Crist

ABSTRACT

Ground water is being extensively developed for domestic, agricultural, and industrial use in a 2,320-square-mile area in Laramie County bounded approximately by Horse Creek on the north, Nebraska on the east, Colorado on the south, and pre-Tertiary outcrops on the west. Currently (1977) about 47,300 acres of land are irrigated with ground water. Ground-water levels are declining in some areas as much as 4 feet per year. The investigation was made to provide State water administrators with data on water-level changes resulting from present (1977) ground-water withdrawals and to provide a means of predicting the future effect of ground-water development.

A digital model was developed of the hydrologic system in the post-Cretaceous rocks. The ability of the model to simulate the hydrologic system was determined by comparing the water-level changes measured at 37 observation wells located in areas of irrigation pumping with the water-level changes calculated by the model for 1971-77. Comparison of the measured and calculated changes showed agreement with a root-mean-square deviation of ±3.6 feet with 8 feet as the maximum deviation. It is concluded that the model adequately simulates present hydrologic conditions in the post-Cretaceous rocks and may be used to predict the effect of applied stress to the system.

INTRODUCTION

Ground water is being extensively developed for domestic, agricultural, and industrial use in a 2,320-mi^2 area in Laramie County (fig. 1) bounded approximately by Horse Creek on the north, Nebraska on the east, Colorado on the south, and pre-Tertiary outcrops on the west. Development for municipal use has not increased appreciably during 1947-77. However, the number of acres irrigated with ground water has increased substantially since about 1969 (fig. 2), and there is concern that additonal development could have an adverse affect upon the ground-water levels in the area. In February 1977, the Wyoming State Engineer upon recommendation of the Wyoming State Board of Control imposed a moratorium on additional ground-water development in Ranges 60 through 65 West and Townships 12 through part of 17 North except for small capacity (yields less than 50 gal/min) stock, domestic, and miscellaneous-use wells. A study was needed to provide information on the effect of current and future ground-water development upon ground-water levels.

Purpose and Scope

The purpose of this investigation is to provide State water administrators with data on water-level changes resulting from ground-water withdrawals and to provide them with a means of predicting future water-level changes resulting from ground-water development. Using existing data, a digital model was developed to simulate the ground-water system in the post-Cretaceous rocks.

Previous Investigations

Numerous investigations were cited by Lowry and Crist (1967, p. 3) in their investigation of the geology and ground-water resources of Laramie County. Since that time, Crist and Borchert (1972) described the ground-water system in more detail in southeastern Laramie County, and Borchert (1976) studied the geohydrology of the Albin, Wyo., area.

Methods of Investigation

Water-level measurements made in March 1977 were used in developing a potentiometric-surface map. Some water-level measurements were made in Colorado and Nebraska so that the potentometric surface (the level to which water will rise in tightly cased wells) could be mapped across the State lines. Data from electric logs of about 100 oil- and gas-test wells were used to define the contact between the Tertiary and Cretaceous formations. These data were used in conjunction with the potentiometric-surface map to estimate the saturated thickness of sediments overlying the Cretaceous rocks. The post-Cretaceous rocks, where present and saturated, are assumed to constitute a single aquifer system because insufficient geohydrologic data are available to define thickness, areal extent, and hydraulic characteristics of individual layers.

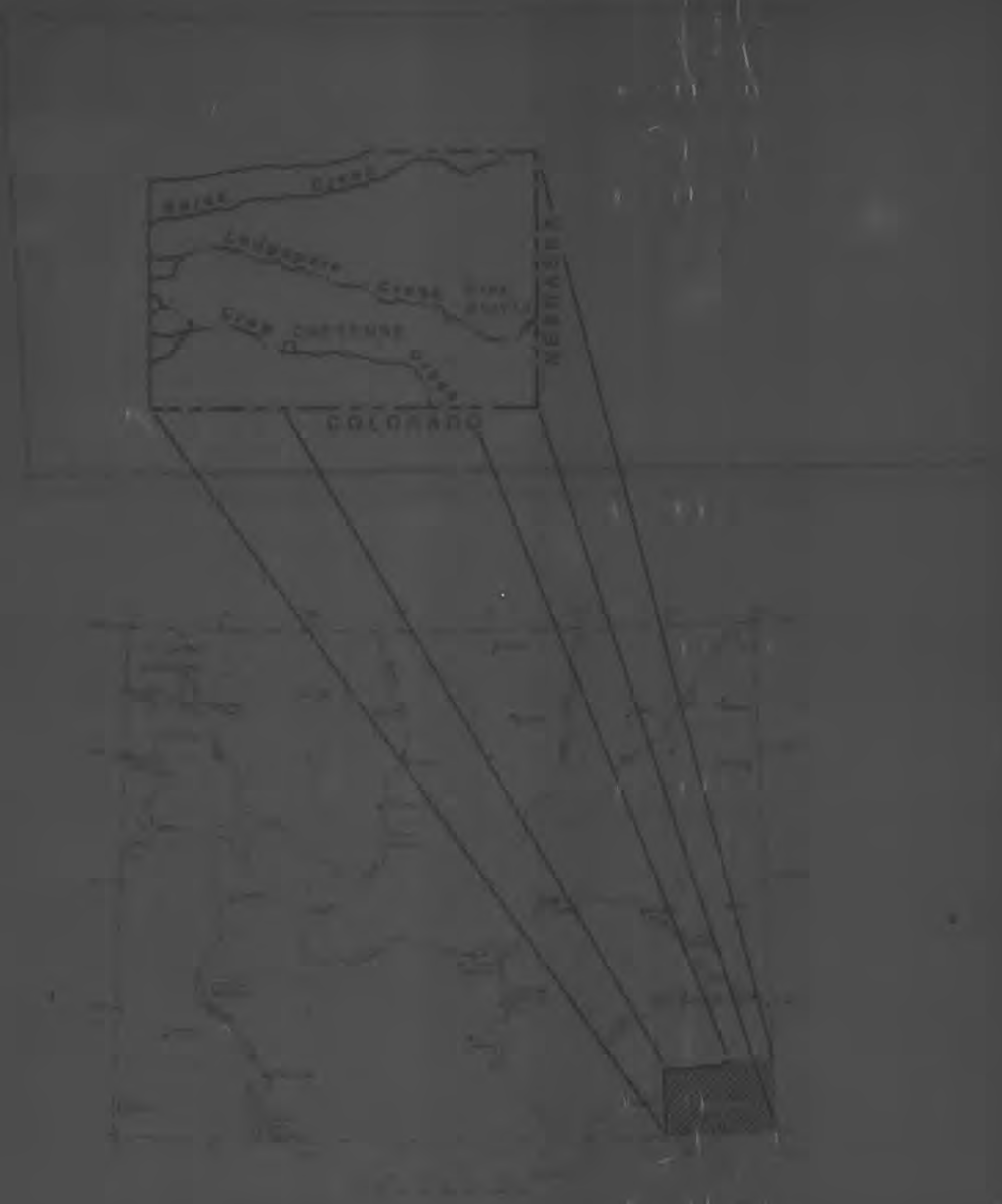


Figure 1.--Location of the area in Wyoming described in this report.

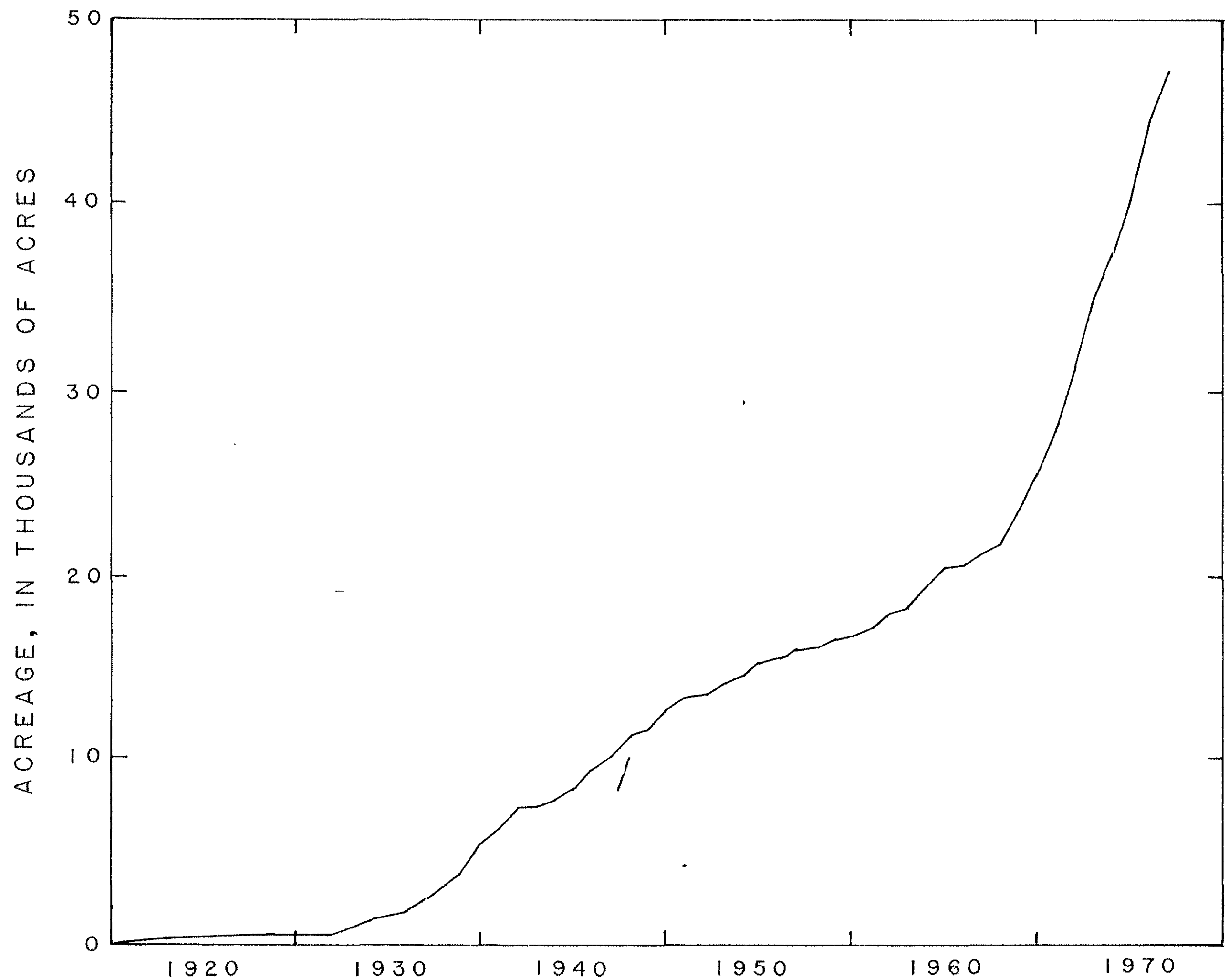


Figure 2.--Estimated cumulative acreage irrigated with ground water, 1920-77. (Wyoming State Engineer, written communication, 1977)

The inventory of wells used for irrigation, industrial, and municipal supplies was updated in 1977. Pumpage records are maintained for most of the municipal and industrial useage. Irrigation pumpage was estimated from irrigated-acreage records of the Wyoming State Engineer's office. Estimates of ground water lost to streams were made on the basis of seepage runs made during November 1976.

A network of 80 observation wells, including 21 wells with digital water-stage recorders, was used to monitor water levels in the study area. (See pl. 1.) Water levels were measured monthly from March 1977 through December 1978 in the observation wells without digital water-stage recorders. The Wyoming State Engineer's office drilled nine of the observation wells in 1977 and installed digital water-stage recorders on these wells in April 1978. Water levels measured periodically in the observation wells are published in reports by Ringen (1973; 1974); Ballance and Freudenthal (1975; 1976; 1977); and Stevens (1978).

Acknowledgments

The author thanks the many residents in the area who permitted U.S. Geological Survey and Wyoming State Engineer's office personnel to measure water levels in wells. Personnel from the Wyoming State Engineer's office made monthly measurements in about 80 observation wells and provided maps of the irrigated acreage in the project area. Ray Sherard, Director of the Cheyenne Board of Public Utilities, retired, provided information on water use by the city of Cheyenne.

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. 3). The first number indicates the township, the second the range, and the third the section in which the well is located. Lowercase letters following the section number indicate the position 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 lowercase letter of the well number. If a section does not measure 1-mi square, it is treated as a full section with the southeast section corner serving as the reference point for the subdivision of the section.

GEOHYDROLOGY

All the post-Cretaceous formations are considered as one hydrologic unit because stratified layers are discontinuous regionally and separate aquifers cannot be identified from available data. Wells are completed in each of the geologic formations younger than Cretaceous age. These

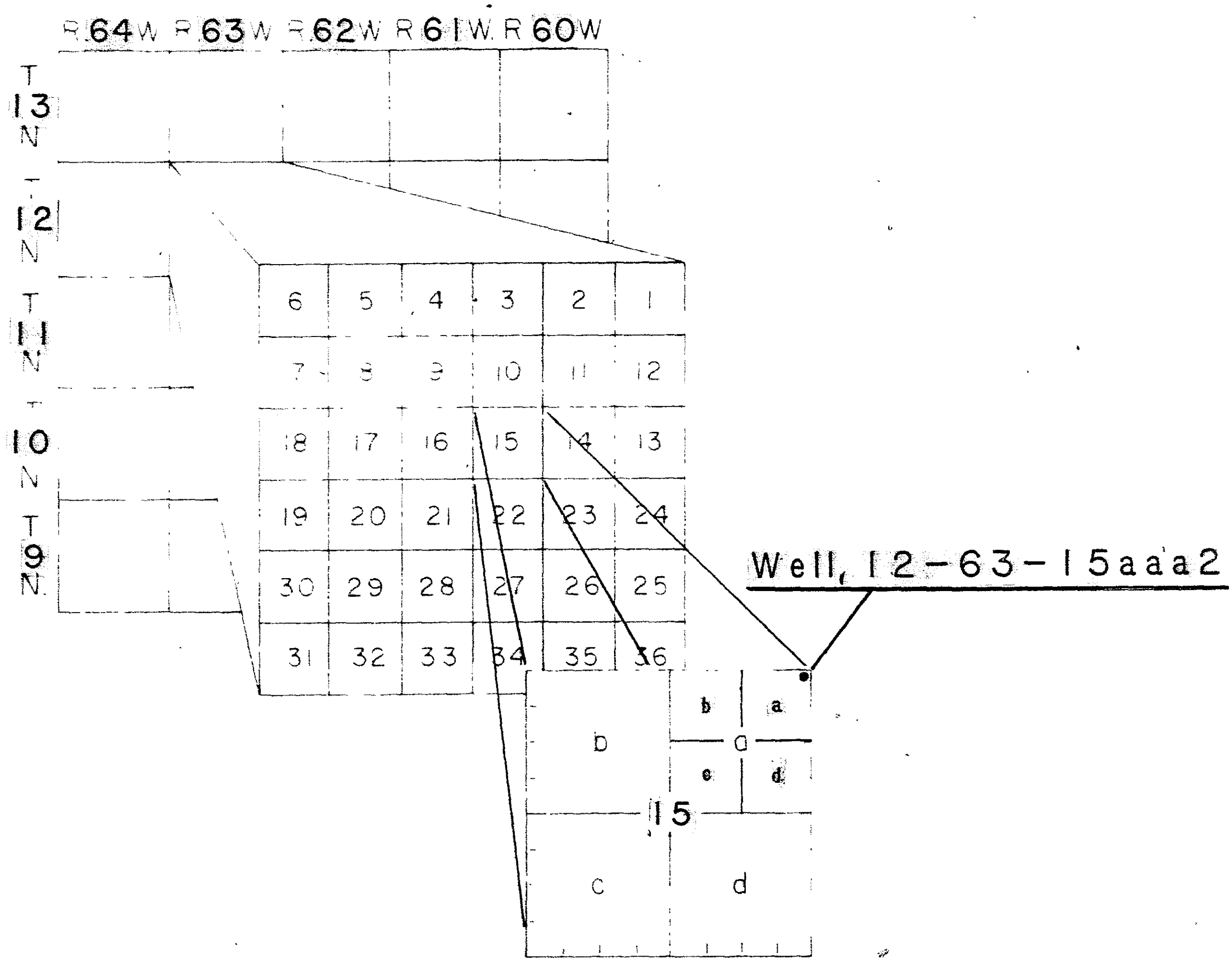


Figure 3.--System of numbering wells.

formations from oldest to youngest are the White River Formation of Oligocene age, the Arikaree Formation of early Miocene age, the Ogallala Formation of late Miocene age, and sediments of Quaternary age.

The White River Formation consists primarily of pinkish-brown massive siltstone containing beds of sandstone, conglomerate, and volcanic ash. Red and green clays and coarse channel deposits occur near the base (Lowry and Crist, 1967, p. 13).

The Arikaree Formation is predominantly a very fine grained, massive sandstone that contains beds of siltstone, layers of hard concretionary sandstone, and thin beds of volcanic ash. A coarse conglomerate occurs at the base in some areas.

The Ogallala Formation consists of a heterogeneous mixture of sand and gravel beds, silt, clay, and thin limestone beds. In places, the beds are cemented by calcium carbonate.

The Quaternary sediments include alluvial deposits underlying terraces and flood plains. The sediments consist of lenticular beds of clay, silt, sand, gravel, and boulders.

All these post-Cretaceous formations are exposed within the study area (pl. 2). The configuration of the base of the post-Cretaceous formations, represented by the contours on plate 2, is based on data obtained from about 100 oil- and gas-test electric logs and lithologic logs of other types of test holes. The greatest intrinsic permeability (a measure of the relative ease with which a porous medium can transmit a liquid under a potential gradient) occurs in beds of sand and gravel in all the units except the White River Formation. In the White River Formation, the greatest intrinsic permeability occurs where secondary permeability has developed as the result of fractures, piping (Lowry, 1966), and solution activity (Crist and Borchert, 1972). The secondary permeability appears to occur only in some areas where the Ogallala and Arikaree Formations have been eroded away and younger alluvial material has been deposited on the White River Formation.

M. E. Cooley prepared a fence diagram (Cooley and Crist, 1980) of the area of investigation showing the relative location of the post-Cretaceous formations. Cooley showed a sand, sandstone, and gravel interval in the White River Formation. This interval can be seen in some electric logs (fig. 4). Away from areas where secondary permeability exists, this interval has the most potential for yielding water to wells. Sufficient test-hole logs were not available to map the sequence throughout the study area. However, a low resistivity zone at the top of the Cretaceous rocks can be identified on most of the logs examined. Cooley refers to this zone as a paleosol. Drill cuttings from other wells show that this zone is predominantly dark-brown shale.

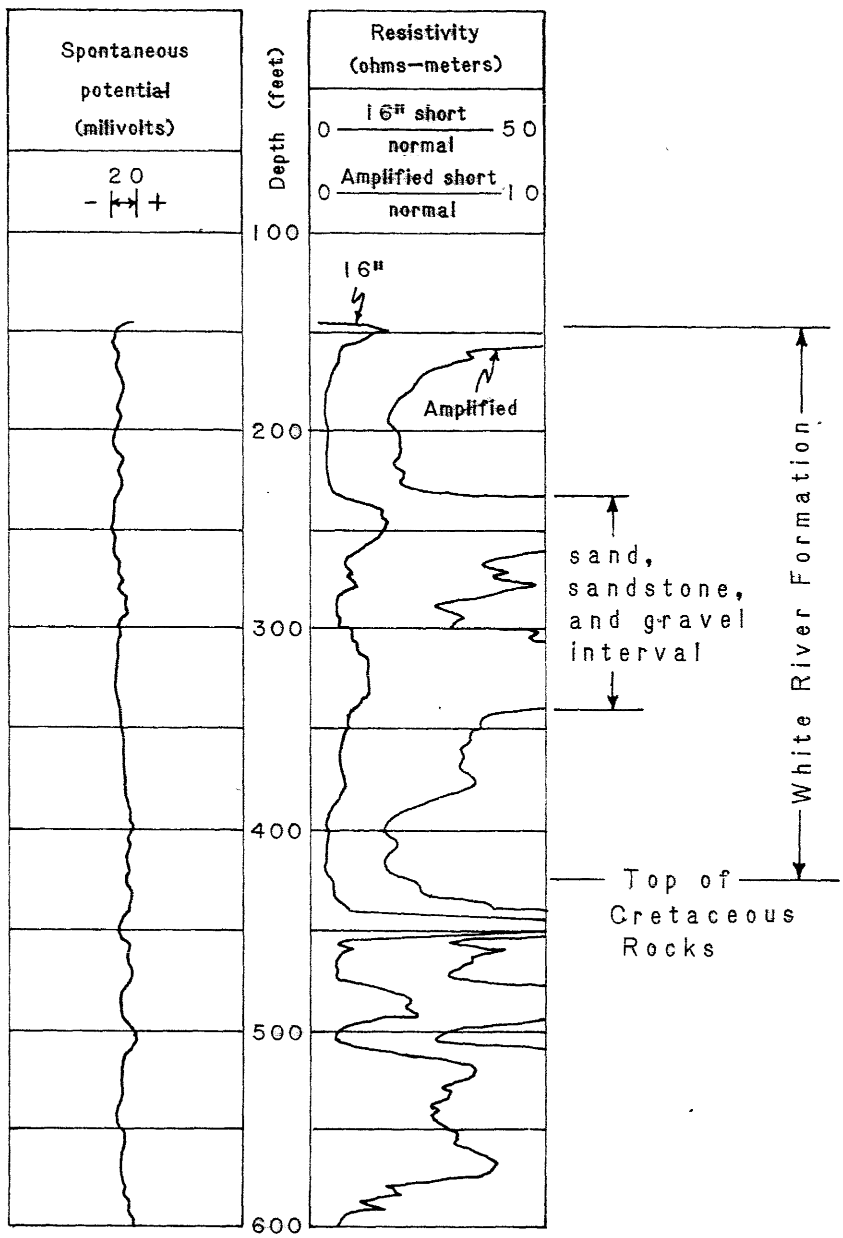


Figure 4.--Electric log of oil-test well 13-61-8bd. Datum is 12 feet above land surface. Reproduced in part from a log by Schlumberger Well Surveying Corp.

Potentiometric Surface

The potentiometric surface is the surface that represents the hydraulic head of water moving through the aquifer system. Hydraulic interconnection within the post-Cretaceous rocks is assumed to be sufficient to permit contouring one continuous water-level surface throughout the study area (pl. 3). The degree of hydraulic interconnection may change from place to place and may be the cause of local abrupt changes in the slope or shape of the potentiometric surface. Regionally, water-table conditions rather than artesian conditions prevail. That is, the water level in a well generally does not rise above the level at which it was encountered while drilling the well.

Ground-water movement is downgradient in the direction of maximum slope of the potentiometric surface. The general direction of movement is along lines perpendicular to the potentiometric contours. The contours on plate 3, drawn from water-level data given on plate 4, show that the ground-water movement is generally west to east with local variations in direction.

The rate of ground-water movement depends on the slope (hydraulic gradient) of the water-level surface, the permeability of the aquifer, and the size of the cross section through which it moves. If the amount of water moving through a given cross section of an aquifer is constant, steepening of the hydraulic gradient (contours spaced closer together) indicates smaller permeability; flattening of the hydraulic gradient (contours spaced farther apart) indicates larger permeability.

Configuration

The configuration of the potentiometric surface is affected by surface drainage. This is particularly noticeable along the upstream reaches of Crow and Horse Creeks and the downstream reach of Lodgepole Creek. The contours (pl. 3) show that Crow Creek is a gaining stream in the upstream reach and a losing stream east of Cheyenne, Wyo. Horse Creek is a gaining stream along most of its course within the study area. Lodgepole Creek is an intermittent stream across most of the study area with short reaches in Wyoming that are perennial. After entering Nebraska, Lodgepole Creek receives enough ground-water discharge to remain perennial to the edge of the modeled area.

The potentiometric-surface map is representative of the ground-water levels during March 1977. The map was prepared using measurements made during early spring when water levels are most stable--that is, not fluctuating rapidly as a result of sudden changes of recharge or discharge as might occur during the irrigation season.

Abrupt changes occur in the potentiometric-surface gradient, such as west of Carpenter, Wyo., and south of Pine Bluffs, Wyo. These two areas occur along an escarpment that is typically present along the edge of the Ogallala Formation where it has been eroded away to expose the underlying formations. Because few springs exist along the Ogallala-White River contact, it is assumed that the steep potentiometric-surface gradient indicates water movement from the overlying Ogallala into lower beds.

Water-Level Trends

The water level in wells fluctuates in response to changes in the amount of ground water in storage. Hydrographs for six observation wells (figs. 5, 6, and 7) are representative of the water-level fluctuations in areas of irrigation pumping.

Increased flow in Crow Creek resulting from increased discharge from Cheyenne's municipal sewage treatment plant is the probable cause of the rising water levels in wells 12-62-5cbb and 12-62-10bbc during 1970-75 (fig. 5). Both wells reflect increased recharge causing a rising water level even though pumping increased in the area.

Water levels in well 12-63-15aaa2 were first measured in 1971 before irrigation pumping began southwest of Carpenter. A hydrograph of the data (fig. 6) shows the water level in this well has declined an average of about 4 ft per year since 1973.

The hydrograph for well 13-60-5ccb indicates that the water level in the area southwest of Pine Bluffs has declined at an average rate of about 4 ft per year from 1974 to 1978. Northwest of Pine Bluffs at well 14-60-5bcb (fig. 7), the water level has declined only about 4 ft during the past 8 years. The water level in well 17-60-34cbb southeast of Albin has declined almost 11 ft during 1972-78.

Landsat Imagery

Landsat (formerly ERTS) satellites were first launched in 1972. These satellites orbit the earth at an altitude of about 559 mi. Imagery obtained from this altitude reveals some features not easily detected on lower altitude aerial photographs or on the ground.

M. E. Cooley mapped lineaments (lines on aerial photos or imagery that are structurally controlled) on Landsat imagery of the study area (fig. 8). On the same map he plotted irrigation wells and springs that could be located on the imagery. Most of the springs appear to be associated with lineaments, but it is difficult to determine if the locations of irrigation wells are related to the linear features.

An overlay of the potentiometric-surface contours on the map of lineaments (fig. 9) shows some correlation between the orientation of the lineaments and the direction of ground-water movement. Ground-water movement is somewhat parallel to the lineaments. Areas of concentrated lineaments or areas of intersecting lineaments may be places to prospect for large quantities of ground water. If the same areas are associated with larger transmissivities (product of hydraulic conductivity and saturated thickness) as indicated by relatively wider-spaced potentiometric-surface contours, the chances are increased for locating and developing wells with individual yields of 500 to 1,000 gal/min.

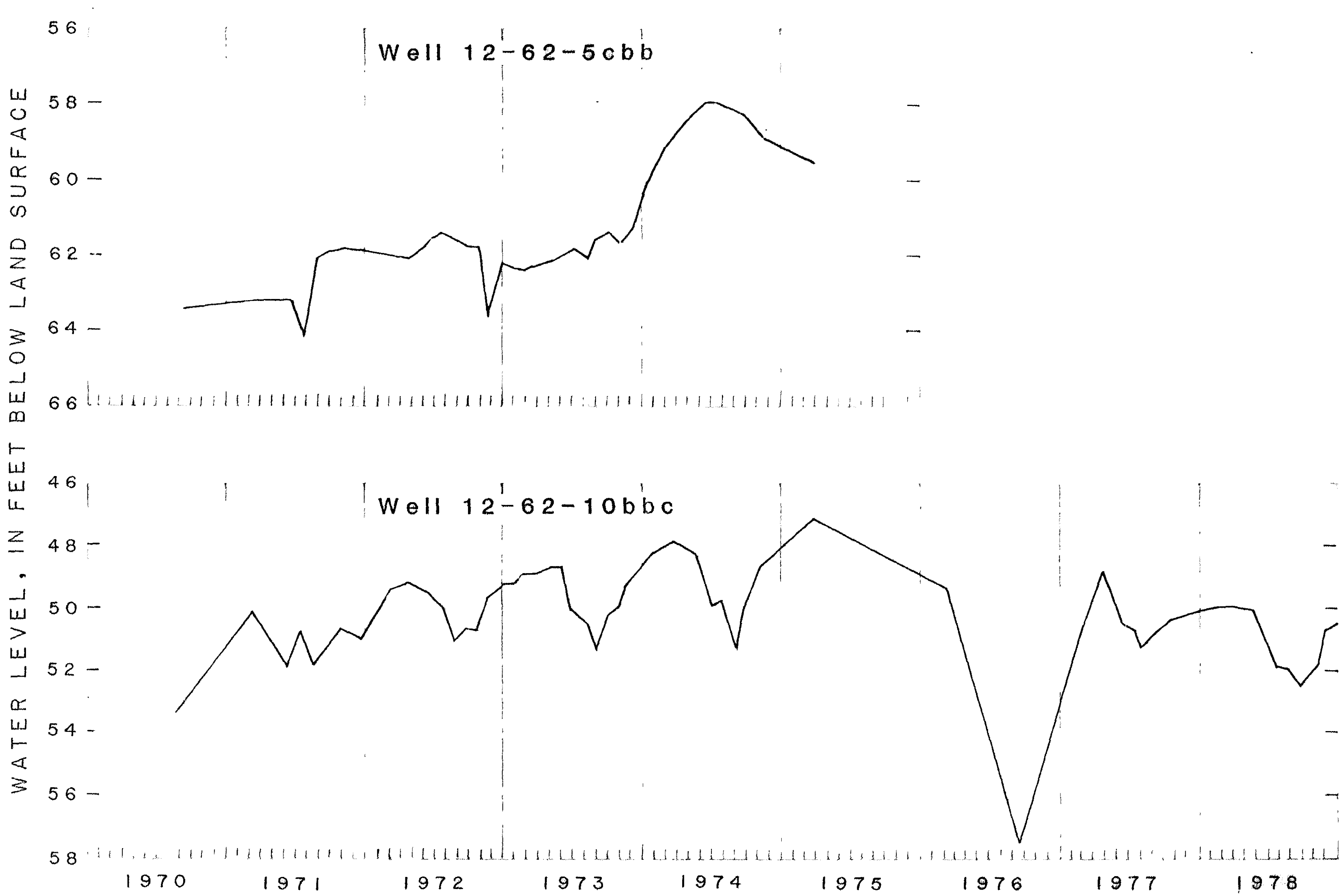


Figure 5.--Water levels in two observation wells that indicate recharge near Carpenter, Wyo.

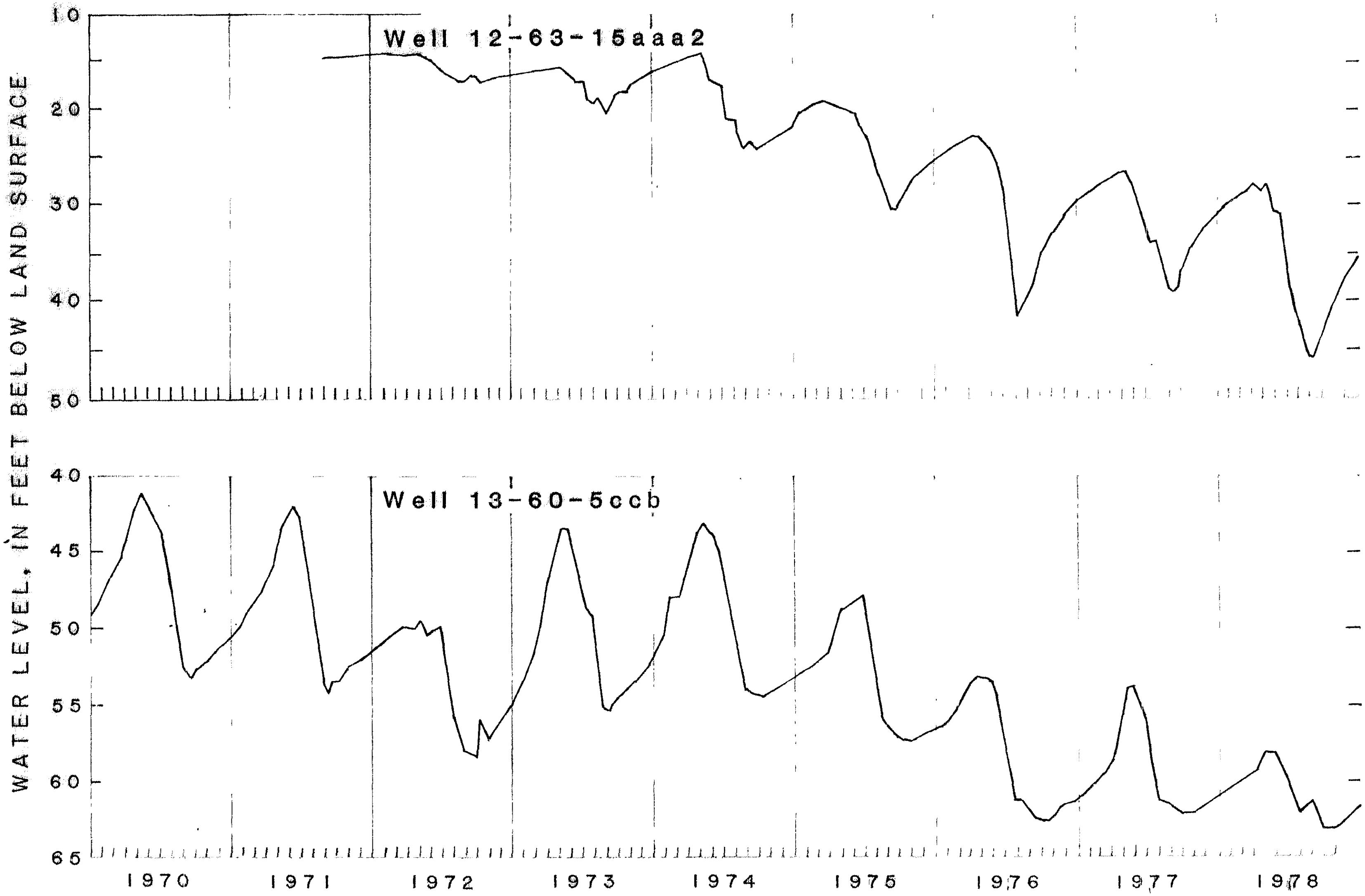


Figure 6.--Water levels in observation wells near irrigation pumping southwest of Carpenter, Wyo. and southwest of Pine Bluffs, Wyo.

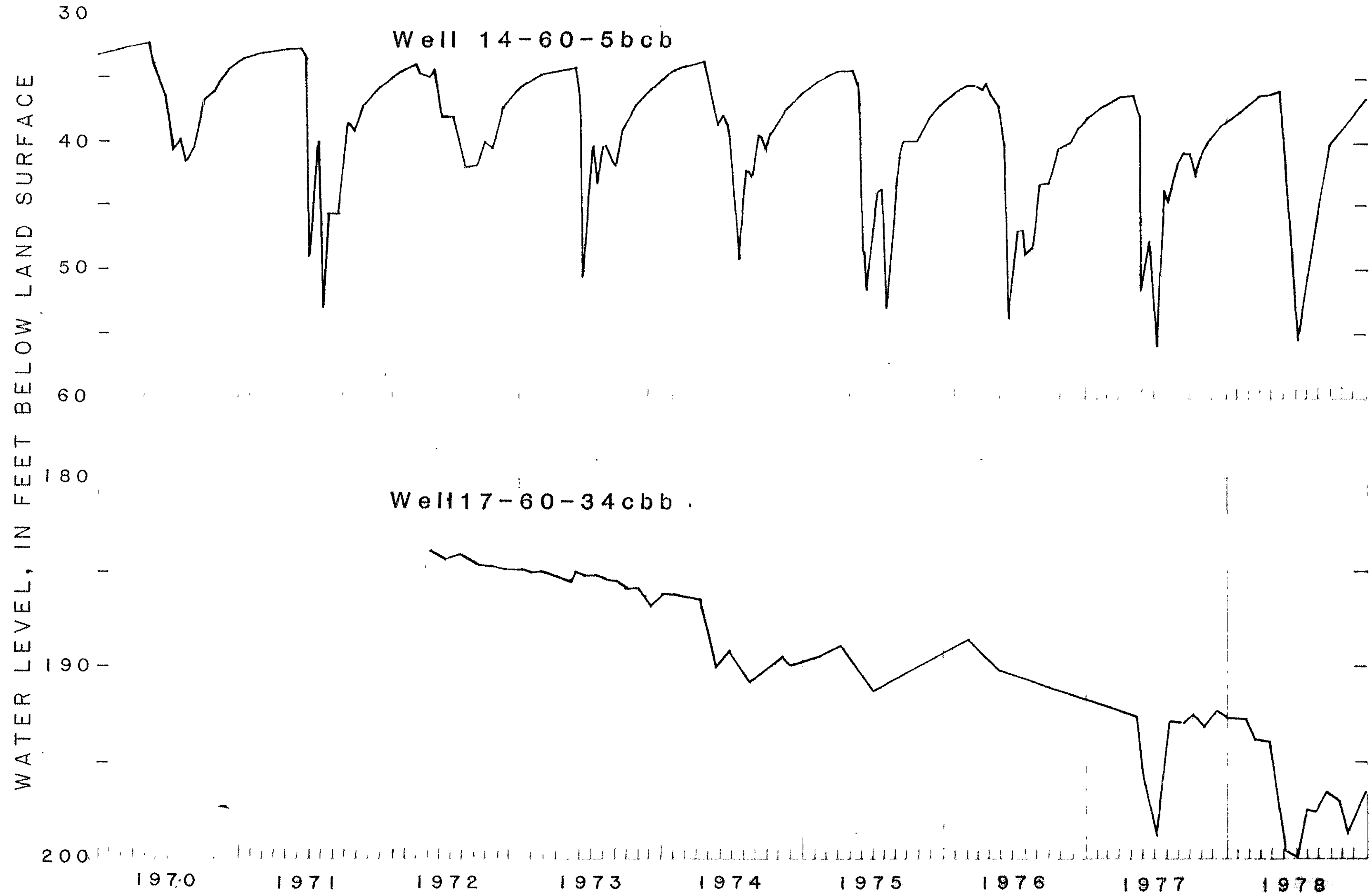
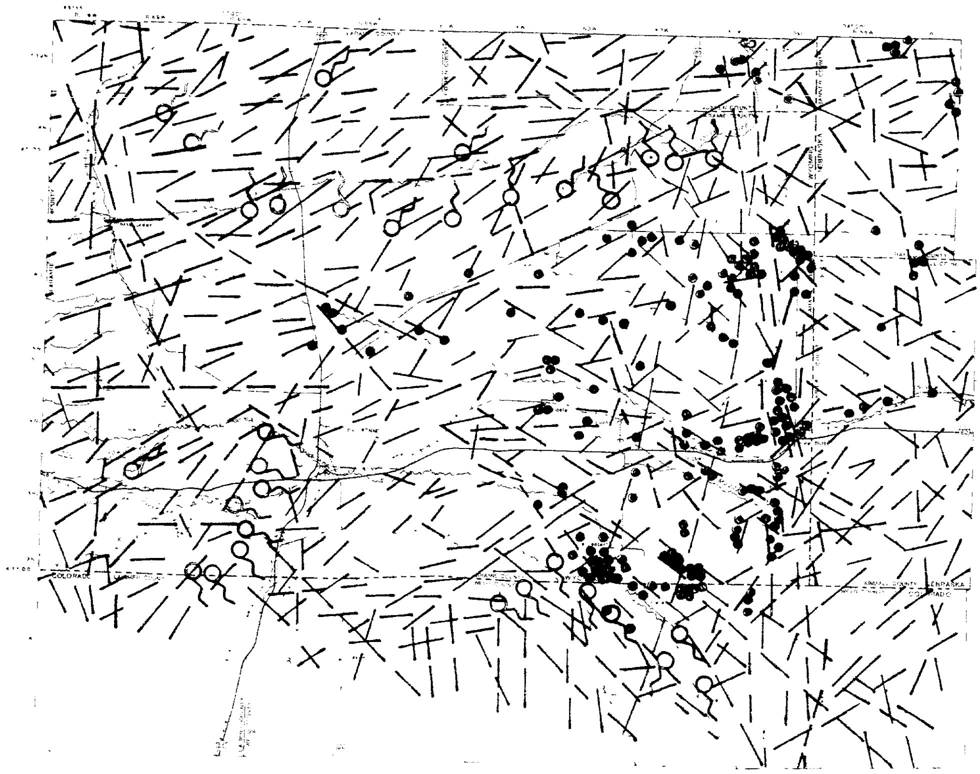


Figure 7.--Water levels in observation wells near irrigation pumping northwest of Pine Bluffs, Wyo. and southeast of Albin, Wyo.



Lineaments by
M. E. Cooley,
1978

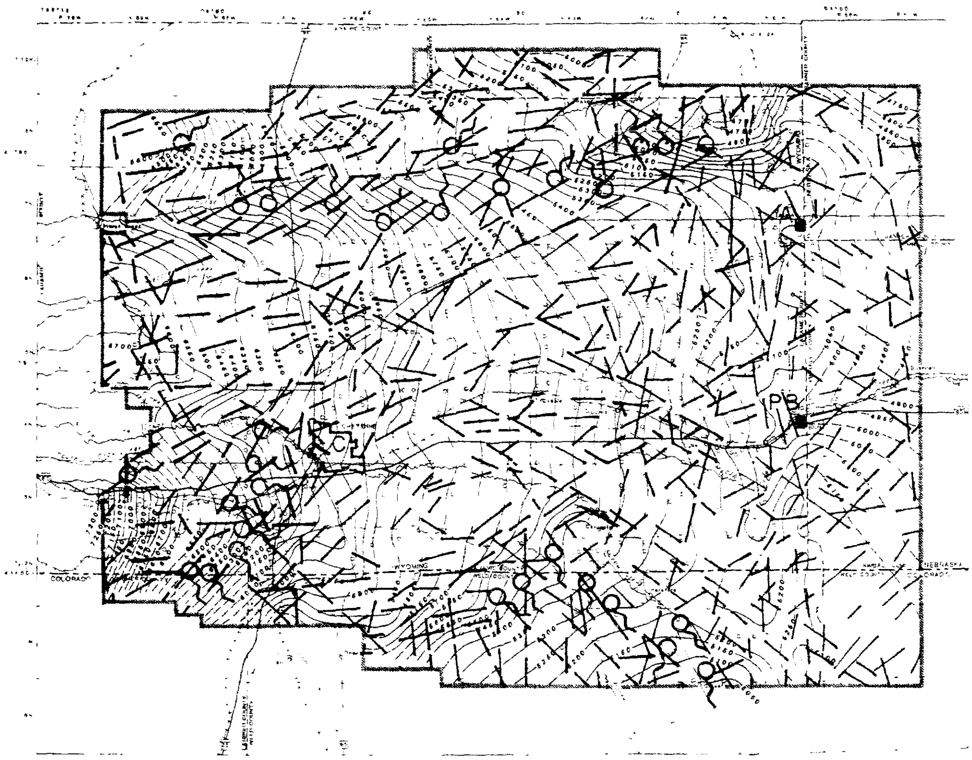
EXPLANATION

— LINEAMENT

• APPROXIMATE LOCATION
OF IRRIGATION WELL

O~ SPRING

Figure 8.--Lineaments, springs, and irrigation wells interpreted from Landsat imagery.



Lineaments by
M. E. Cooley,
1978

EXPLANATION

—— *4800* ---POTENTIOMETRIC-SURFACE CONTOUR-- Shows altitude at which water level would have stood in wells during March 1977. Dashed where approximately located. Contour interval 50 feet. Datum is National Geodetic Vertical Datum of 1929.

WATER-LEVEL CONTROL POINT

SPRING

LINEAMENT

CITY OR TOWN

A Albin

C Cheyenne

PB Pine Bluffs

Figure 9.--Correlation of the direction of ground-water movement and lineaments.

MODELED AREA

The modeled area (pl. 2) extends from the pre-Tertiary outcrops on the west to about 11 mi into Nebraska on the east and from 3 to 7 mi north of Horse Creek on the north to the pre-Tertiary outcrops about 9 mi into Colorado on the south. Where the model boundary does not coincide approximately with the edge of the post-Cretaceous rocks, the boundary is placed far enough away so that effects of stress imposed on the model do not reach the boundary. Although the model includes parts of Nebraska and Colorado, the area of principal interest is the post-Cretaceous rocks in Laramie County. Hereafter, all quantitative data are given only for that part of the model in Laramie County.

Recharge is received from precipitation, from streams, and as underflow (underflow in this report refers to water that moves through the subsurface) moving across the model boundaries. The average of the normal precipitation recorded at seven locations in Laramie County is about 15 in. annually. Morgan (1946, p. 19) estimated recharge from precipitation to be about 0.83 in. per year in the vicinity of Cheyenne, or about 5.5 percent of the average precipitation.

Leakage occurs between the streams and the ground-water reservoir. Configuration of the potentiometric surface indicates the gaining and losing reaches of the streams.

The principal streams in the area are Crow Creek, Lodgepole Creek, and Horse Creek with the latter being the only perennial stream throughout its course across the county. The city of Cheyenne discharges an average of about 8,000 acre-ft of water per year into Crow Creek from the municipal sewage treatment plant located in sec. 6, T. 13 N., R. 65 W. Part of the municipal water is obtained from wells west of the city, part from surface runoff collected in reservoirs on Crow Creek tributaries, and part is imported from the Medicine Bow Mountains about 100 miles west of Cheyenne.

It is assumed that all the municipal discharge is recharged to the ground-water reservoir downgradient from the sewage treatment plant. Surface flow in Crow Creek ceases in sec. 36, T. 13 N., R. 63 W. where it seeps into the Quaternary deposits, except during periods of high runoff. The Wyoming State Engineer's office (written commun., 1973) made seepage runs on Crow Creek during a period of high runoff and found that the stream can lose as much as 13 ft^3/s near Carpenter.

Water leaves the ground-water reservoir in the county by discharging to streams, by pumpage, and by underflow. Seepage runs were made on all the streams in November 1976 to estimate base flow (that part of stream discharge that is ground-water discharge). Evapotranspiration losses at this time of year are considered to be negligible and were ignored.

Consumptive use for irrigation is estimated to be 1.2 acre-ft per acre annually. This is based on the average of the consumptive irrigation requirement for crops grown at Cheyenne and Pine Bluffs (Trelease and others, 1970). During 1977, estimated pumpage was 56,800 acre-ft for irrigation, 4,300 acre-ft for municipal use, and 650 acre-ft for industrial use.

The volume of water entering and leaving the county as underflow is calculated by the model and is commensurate with the transmissivity and the hydraulic gradient.

DIGITAL MODEL

The digital model simulates the hydrologic conditions in the post-Cretaceous rocks. Major stresses on the system are caused by recharge from precipitation and by discharge through pumpage for domestic, municipal, industrial, and agricultural use.

The general computer program for the model was written by Trescott and others, (1976). Hoxie (1977, p. 21) modified the program to include a streamflow-accounting procedure by which the interaction between the streams and the aquifer is approximated.

A finite-difference approximation of the differential equation for two-dimensional ground-water flow in an aquifer as derived by Pinder and Bredehoeft (1968) was used to calculate the head distribution, underflow, and leakage. The area was subdivided into variable-sized rectangular cells to form a grid (fig. 10). The center of each cell is a node. Data that describe the hydrologic system (hydraulic properties, hydraulic-head distribution, recharge, discharge, and streamflow) were supplied for each node as initial conditions at the start of simulation. A digital computer was used to solve the finite-difference equation for each node in the grid, utilizing the strongly implicit procedure (Stone, 1968).

The principal assumptions made for the model development follow:

1. Regionally, the vertical-flow velocity within the aquifer was assumed to be negligible in comparison to the horizontal-flow velocity; therefore, flow was considered to be two dimensional.

2. All the post-Cretaceous rocks were assumed to constitute a single aquifer as all the formations are hydraulically interconnected regionally and there are insufficient data available to define separate layers.

3. Specific yield (the ratio of the volume of water that a rock, after being saturated, will yield by gravity drainage to the volume of rock) was set equal to zero for steady-state simulations. For transient simulations specific yield was assumed to be 0.15 because of lack of measured data.

Figure 10.—Rectangular grid used to model hydrologic conditions in post-Cretaceous rocks.

4. Recharge from precipitation was estimated to be 0.83 in. per year and was assumed to be uniformly distributed over the model area as no data are available that show quantitative differences in recharge from place to place.

5. The potentiometric surface mapped from measured water levels (pl. 3) was assumed to approximate the potentiometric surface during steady-state conditions.

6. Leakage between the streams and the ground-water reservoir was assumed to occur at the rate estimated from seepage runs made during November 1976.

Steady-State Procedures

Steady-state procedure involves selecting data for the model such that the calculated hydraulic-head distribution (fig. 11) and stream discharge agree, within acceptable limits, with values measured in the physical system. Depth of the streams was assumed to be 1 ft. Input streamflow was entered for the principal streams entering from the west. After starting the steady-state simulation, the streamflow-accounting procedure maintained a cumulative total of the losses and gains calculated for each stream cell. A stream cell could not lose more water than the cumulative total in that cell. However, a stream cell could gain an amount commensurate with the hydraulic gradient of the potentiometric surface, the hydraulic-head difference between the stream and the aquifer, the transmissivity of the aquifer, the thickness and hydraulic conductivity of the streambed, and the gradient of the stream between stream cells. Streambed thickness was assumed to be 1 ft and its hydraulic conductivity was assumed to be 2.7 ft/d. Hydraulic conditions of the streambed were assumed to be similar enough to those in the Arkansas River in Colorado that the same leakage rate (Moore and Jenkins, 1966) could be used.

Assuming all data except aquifer hydraulic conductivity are correct for steady-state conditions, then the hydraulic-conductivity distribution can be generated by trial and error. The trial and error procedure is continued until the hydraulic-head distribution and stream discharge calculated by the model agree, within acceptable limits, with the values determined for the real system. Values of hydraulic conductivity determined from this procedure range from 1×10^{-6} to 5×10^{-3}ft/s. Comparison of plates 3 and 5 shows that the computed hydraulic-head distribution agrees favorably with the measured hydraulic-head distribution.

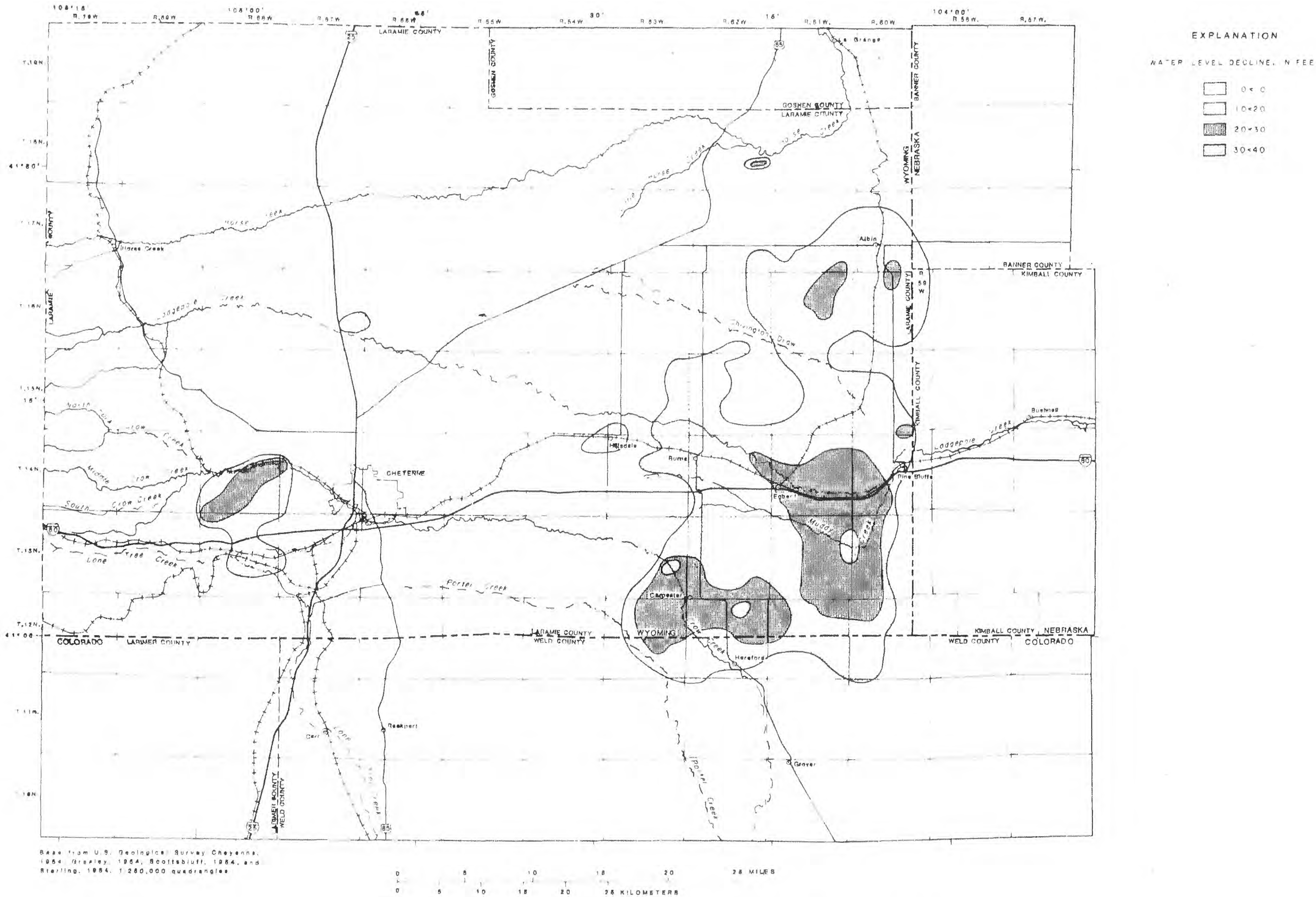


Figure 11.--Water-level changes calculated for 1920-87.

Under steady-state conditions, the following water budget was estimated for that part of the model in Laramie County:

Recharge

		Acre-ft per year
Precipitation		102,700
Underflow		1,400
Streamflow		3,200
	Total	107,300

Discharge

Underflow		86,200
Streamflow		21,100
	Total	107,300

Transient Procedures

The digital model can be checked with transient simulations by comparing calculated water-level changes with measured water-level changes. The actual hydraulic-head distribution prior to pumping (1920) is not available but has been created during the steady-state procedures. For transient simulations, the calculated steady-state hydraulic-head distribution was used as the initial hydraulic-head distribution and was tested by stressing the model for the period 1920-77 with the estimated pumpage for that period. A variable time step was used for transient simulation. The initial time step was 24 hours and each subsequent time step was 1.5 times greater than the previous one.

No water-level-change maps are available for the study area, but water-levels have been measured in 37 observation wells (fig. 10) from about 1971 through 1977. For this period, the average difference between the calculated water-level changes and the measured changes at these wells was obtained with the following equation:

$$rms = \left[\frac{1}{N} \sum_{i=1}^{N} (h_i - h_i^o)^2 \right]^{\frac{1}{2}} \qquad (1)$$

where

rms = root-mean-square ;
N = total number of nodes;
i = an index numbering nodes sequentially from 1 to N;
h = calculated hydraulic head, in feet; and
h^o = measured hydraulic head, in feet.

The average difference is referred to as the rms deviation and is a measure of the departure of the calculated hydraulic head from the measured hydraulic head. Comparison of the calculated and measured changes at these wells showed an agreement with a rms deviation of ±3.6 ft with a maximum deviation of 8 ft. Simulation of the 7-year period was used to test the accuracy of the model. These observation wells are distributed in the localities of irrigation pumping that are the only places where significant water-level fluctuations occur. Although the accuracy of the individual data in the model is unknown, the result of the combination of values used appears to adequately simulate the hydrologic system in the vicinity of the observation wells.

The model was tested for sensitivity by making 20-percent changes in pumpage and specific yield. On the basis of water-level changes, these tests showed that the model is about twice as sensitive to changes in pumpage as to changes in specific yield.

A water budget was calculated for that part of the modeled area in Laramie County for 1971 through 1977. The average annual recharge and discharge estimated for the period is given in the following table:

		Acre-ft per year
Recharge		
Precipitation		102,700
Underflow		1,400
Streamflow		3,200
	Total	107,300
Discharge		
Pumpage		43,800
Underflow		73,300
Streamflow		16,400
	Total	133,500

This shows that from 1971-77 discharge averaged 26,200 acre-ft more per year than recharge, resulting in a decrease in ground-water storage. However, the average for the 7 years does not reflect the fact that the annual deficit is increasing each year as annual pumpage withdrawals increase. With reference to figure 2, irrigated acreage increased each year and increasing amounts of water were required. Comparison of the water budgets estimated for steady-state and transient conditions indicate that discharge from the county by underflow and by streams is decreased. The larger part of the pumpage is obtained from storage which results in declining water levels. This is assuming that during a long period natural recharge remains constant.

Prediction Results

On the basis of good agreement between water levels calculated and measured at observation-well locations, it is concluded that the model adequately simulates the hydrologic conditions in the post-Cretaceous rocks in Laramie County and may be used to predict the effect of applied stress to the system.

The model was used to predict the results of pumping through 1987. All pumping was assumed to continue during the final 10-year period (1978-87) at the same rate as was estimated for 1977, with no additional wells added during this period. Water-level changes calculated by the model (fig. 11) indicate declines from 1920 of as much as 30 to 40 ft in areas of pumpage by the end of 1987.

Another simulation was made to indicate the result of irrigating approximately 16,400 acres in addition to the acreage now being irrigated. These lands represent requests for permits, received by the Wyoming State Engineer, to drill additional irrigation or other large-capacity (yields greater than 50 gal/min) wells. The increased pumpage was simulated by the model for 1978-87 and the predicted water-level changes are shown in figure 12. Comparison of the water-level changes mapped in figures 11 and 12 shows how the increased pumpage is expected to affect the water levels. The location of the additional acreage and pumpage used for this simulation is not shown because the simulation is hypothetical and intended only to illustrate how the model might be used as a guide by water administrators in making management decisions.

SUMMARY AND CONCLUSIONS

Agricultural use of ground water in Laramie County was started about 1920. Since 1969 pumpage has increased substantially, and in 1977 about 47,300 acres were irrigated with ground water. Water levels are declining in some areas by as much as 4 ft per year.

In February 1977, the Wyoming State Engineer upon recommendation of the Wyoming State Board of Control imposed a moratorium on additional ground-water development by large capacity (yields greater than 50 gal/min) wells in approximately the eastern one-half of the county. State water administrators needed data on the effect of ground-water withdrawals upon water levels and a means of predicting future water levels resulting from present and future ground-water development.

A digital model of the hydrologic system in the post-Cretaceous rocks was developed. Accuracy of the model to simulate the hydrologic system was determined by comparing the water-level changes measured at 37 observation wells in areas of irrigation pumping with the water-level changes calculated by the model for 1971-77. Comparison of the measured and calculated changes showed an agreement with a root-mean-square deviation of ±3.6 ft with a maximum deviation of 8 ft. On this basis, it is concluded that the model adequately simulates the hydrologic conditions in the post-Cretaceous rocks in Laramie County and may be used to predict the effect of applied stress to the system.

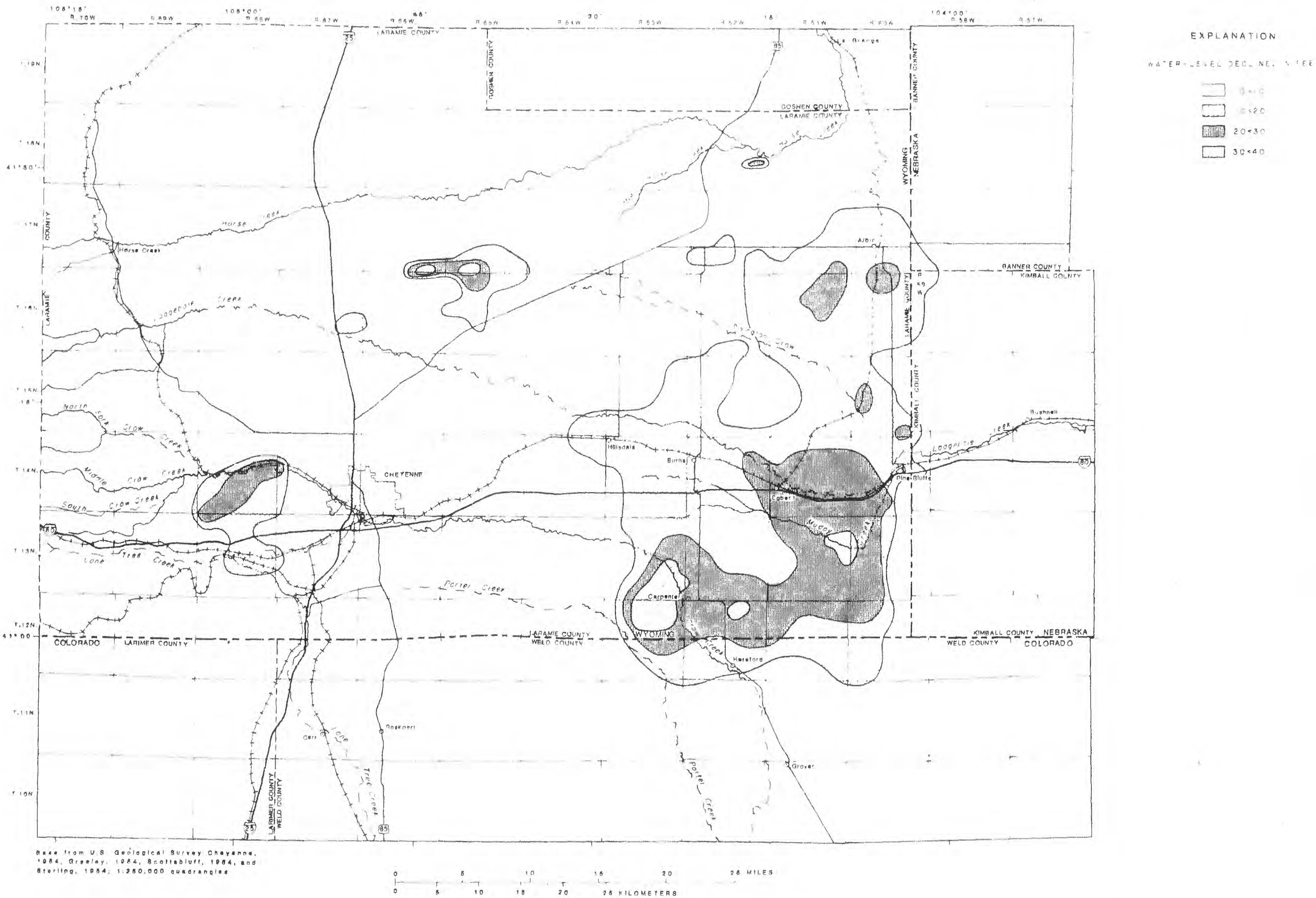


Figure 12.--Water-level changes calculated for 1920-87 assuming increased pumpage after 1977.

The model was used to predict the water-level changes at the end of 1987. Pumping was assumed to continue from 1977 through 1987 at the same rate as was estimated for 1977. Water levels in the vicinity of irrigation wells are expected to continue to decline if pumpage is continued at the same rate.

A hypothetical case of increased pumpage was simulated with the model. Water-level changes resulting from the hypothetical increase in pumpage were mapped to illustrate how the model might be used as a guide by water administrators in making management decisions.

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