HYDROLOGIC EVALUATION OF PROPOSED GROUND-WATER WITHDRAWALS IN MULESHOE FLAT NEAR WHEATLAND, SOUTHEASTERN WYOMING

By Dwight T. Hoxie

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CONVERSION FACTORS AND VERTICAL DATUM

For those readers who may prefer to use metric units, the conversion factors for inch-pound units used in this report are listed below:

Multiply inch-pound unit	By	To obtain metric unit
foot	0.3048	meter
mile	1.609	kilometer
acre	0.4047	hectare
square mile (mi^2)	2.590	square kilometer
acre-foot	0.001233	cubic hectometer
acre-foot per year (acre-ft/yr)	0.001233	cubic hectometer per year
foot per day (ft/d)	0.3048	meter per day
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
cubic foot per second per square mile [$(ft^3/s)/mi^2$]	0.01093	cubic meter per second per square kilometer
gallon per minute (gal/min)	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 mean sea level.

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ABSTRACT

The hydrologic effects of proposed irrigation with ground water of 8,320 acres of land in Muleshoe Flat, a 34-square-mile area in west-central Platte County, Wyo., have been assessed. Results generated by a digital ground-water-flow model indicate that, at the end of a 40-year period, ground-water-level declines of more than 50 feet can be expected in an area of 12.5 square miles and of more than 200 feet in an area of 7 square miles. In addition, streamflow depletions of 4,300 acre-feet per year can be expected in the Laramie River and 4,700 acre-feet per year in Sybille Creek. Additional hydrologic-field-data collection prior to initiation of the proposed irrigation development would improve these assessments. Applications for the proposed irrigation wells were denied subsequent to the data collection and analysis described in this report.

INTRODUCTION

Muleshoe Flat is located in west-central Platte County, Wyo., approximately 8 miles west of the town of Wheatland. It is a triangular-shaped area of 34.2 mi^2, bounded on the south by the Cooney Hills, on the east by Sybille Creek, and on the north and west by the Laramie River (fig. 1). Most of the land within Muleshoe Flat is public domain that is administered by the U.S. Bureau of Land Management. Except for stock grazing in the upland areas and some irrigated crop production on private lands within the stream valleys, no agriculture or other development has occurred within the area.

The Bureau of Land Management requested that the U.S. Geological Survey assess the feasibility of developing ground-water supplies for irrigation within Muleshoe Flat. Twenty-six applications were made for desert land entry pursuant to the Desert Land Act of March 3, 1877. These applications proposed the installation of 76 wells to provide irrigation water to 8,320 acres of land within or immediately adjacent to Muleshoe Flat. Because surface water within the area is fully appropriated, it was planned to supply the water for irrigation from wells. A minimum annual consumption of 12,480 acre-feet of ground water was expected, based on an assumed annual application of 1.5 feet of water per acre of irrigated land. The applications for the proposed irrigation wells were denied subsequent to the data collection and analysis described in this report.

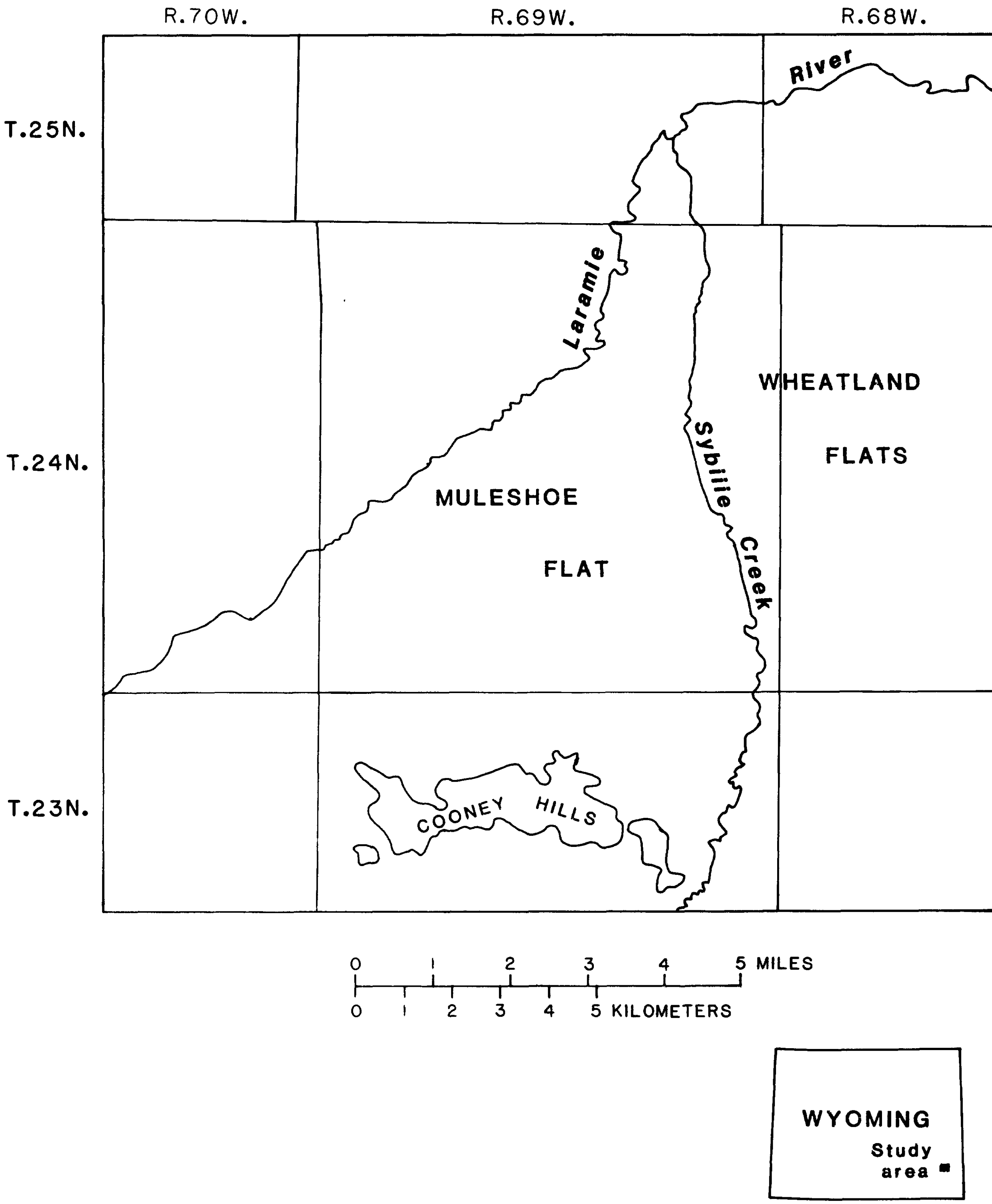


Figure 1.--Area described in this report.

Purpose and Scope

This study estimates the time and spatial distribution of ground-water-level declines and streamflow depletions that may have been expected to occur within the vicinity of Muleshoe Flat as a result of the proposed irrigation development. A hydrogeologic reconnaissance of the study area was undertaken to define the ground-water-flow system and to collect pertinent hydrologic and geologic data. This reconnaisance included cursory mapping of the surface geology, the measurement of streamflows, and the measurement of water levels in wells. A mathematical model was constructed to simulate the ground-water-flow system and its interaction with the Laramie River and Sybille Creek. The proposed irrigation pumpage was imposed on this model to predict the long-term impact of the irrigation development on the combined ground- and surface-water system.

Previous Investigations

The area of this study is included in a report on the geology and ground-water resources of Platte County, Wyo., (Morris and Babcock, 1960). Hydrologic investigations by Weeks (1964), Lines (1976), and Hoxie (1977) involve areas that border Muleshoe Flat; McGrew (1967) mapped the surface geology along the southern border of Muleshoe Flat.

HYDROGEOLOGY

Geologic Setting

Muleshoe Flat is a pediment that slopes northward from the Cooney Hills to the confluence of the Laramie River and Sybille Creek. The pediment is a surface of low relief that has been cut on rocks of Tertiary age. These rocks consist primarily of poorly to well-cemented clastic debris that has been eroded from older rocks in the Cooney Hills to the south and the Laramie Mountains to the west. The Tertiary rocks are locally covered by a veneer of slope wash in the upland areas and by alluvium in the stream valleys. Igneous and metamorphic rocks of Precambrian age are exposed in both the Cooney Hills and the Laramie Mountains and underlie the Tertiary rocks. The Tertiary rocks attain a thickness of as much as 1,200 feet within Muleshoe Flat according to the log of an oil-test well drilled in sec. 10, T. 24 N., R. 69 W.

As shown in figure 2, the Tertiary rocks exposed at the surface are here divided into an upper and a lower unit. Exposures of the lower unit consist of white to gray, poorly to well-cemented, fine-grained sandstone and thin-bedded white limestone. This unit is identified with the Arikaree Formation of early Miocene age as described in nearby areas by McGrew (1953), Morris and Babcock (1960), Weeks (1964), Lines (1976), and Hoxie (1977).

The upper unit shown in figure 2 consists of poorly cemented, buff to gray calcareous sandstone and conglomerate. The unit attains a maximum thickness of about 300 feet where it is exposed on the north side of the Cooney Hills. The upper and lower units are distinguished primarily

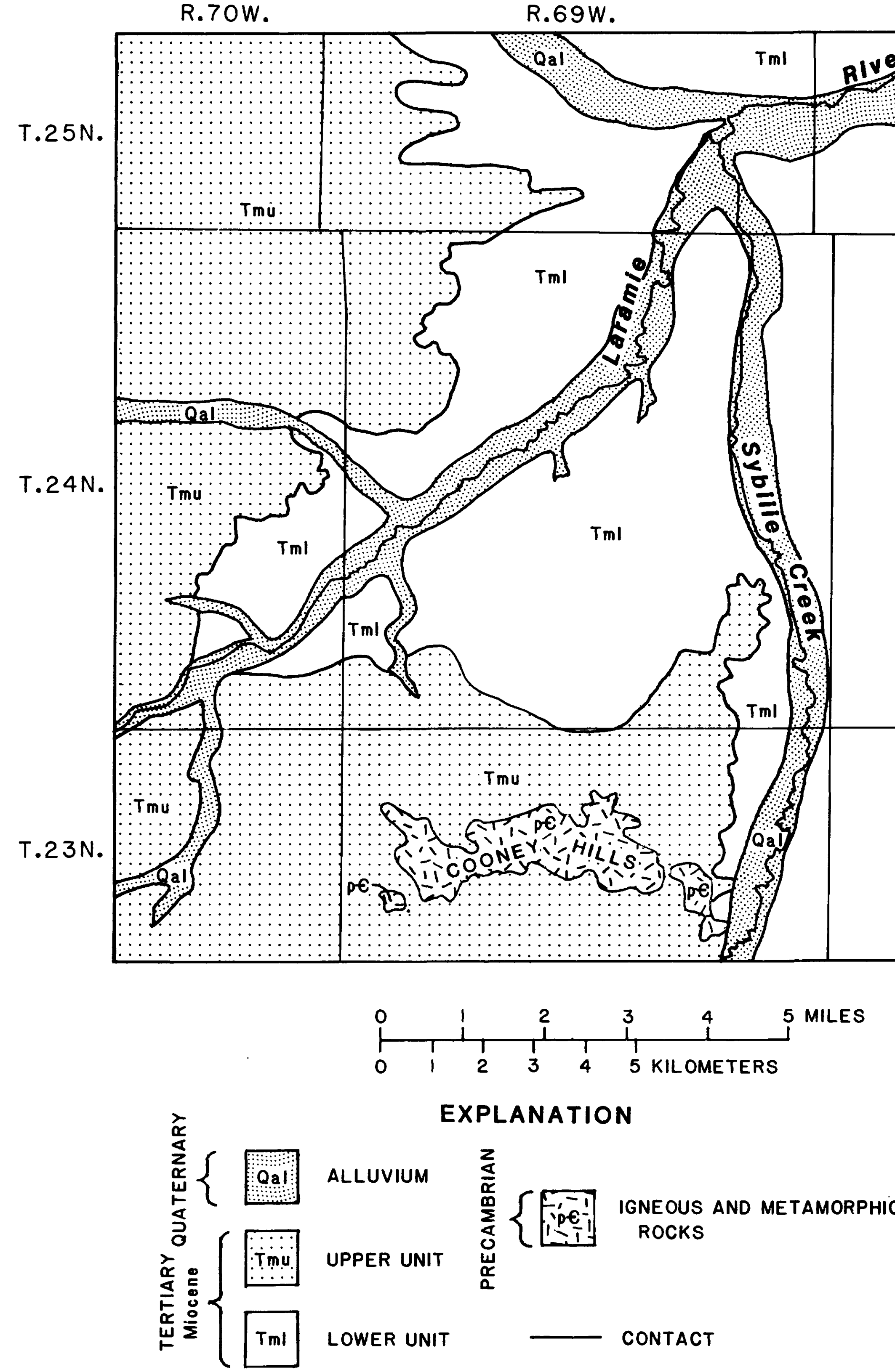


Figure 2.--Generalized distribution of rocks exposed in the study area.

by differences in the degree of induration rather than by differences in lithology. Where the lower unit is exposed, it defines a surface cut on more resistant sandstone and limestone beds. McGrew (1967) included the upper unit here defined as part of an upper unit in the Arikaree Formation; whereas, N. M. Denson (U.S. Geological Survey, written commun., 1978) assigned rocks of similar lithology in the southeastern part of T. 26 N., R. 67 W. to the Ogallala Formation of late Miocene age. Both units are here assigned to the Miocene Series.

Aquifer System

Saturated rocks of Miocene and younger age in Wheatland Flats (Weeks, 1964) and in the area north of Muleshoe Flat (Lines, 1976, and Hoxie, 1977) constitute an unconfined aquifer system, the Arikaree aquifer, that has been tapped by irrigation and municipal wells that yield as much as 500 gal/min. It is assumed that a similar condition prevails within Muleshoe Flat in that the saturated zone within the upper and lower Miocene units mapped in figure 2 constitute an unconfined aquifer that is capable of supplying water to similar high-yield wells. Because no high-yield wells or test wells have been completed within Muleshoe Flat, the hydraulic properties of the aquifer system are largely unknown. It is here assumed that the system possesses hydraulic properties similar to those associated with the Arikaree aquifer in adjacent areas as described by Weeks (1964), Lines (1976), and Hoxie (1977).

Only a few stock wells that pump intermittently at rates of less than 5 gal/min presently withdraw water from the unconfined aquifer underlying Muleshoe Flat. The present ground-water-flow system is presumably one of natural equilibrium in which water that enters the system as recharge is ultimately discharged in the valleys of the Laramie River and Sybille Creek. The rate of discharge and the configuration of the water table fluctuate in time in response to time and spatial variations of recharge over Muleshoe Flat. There is little or no direct evapotranspiration loss from the aquifer and no indication of a significant amount of rejected recharge. Consequently, if wells withdrawing large quantities of water are imposed on the system, the present state of equilibrium will be disrupted. Water to such wells presumably would be supplied initially from water held in storage within the aquifer and from the interception of water that would otherwise discharge to the surface streams. Ultimately, the cones of depression about the pumping wells would be expected to intersect the streams, and streamflow would then be diverted into the aquifer. If the rates of infiltration and the surface flows in the Laramie River and Sybille Creek were sufficient, the system would establish a new equilibrium state in which the water pumped by the wells would be supplied by intercepted ground-water discharge and diverted streamflow. The ground-water-flow model constructed during this study permits the simulation of both the natural and the stressed flow systems to provide a quantitative estimate of the magnitude and time sequence with which these effects of the proposed irrigation pumpage occur. It must be emphasized, however, that the paucity of fundamental hydrologic data for the study area severely restricts the accuracy attainable by the model. The quantitative results and predictions here presented must be viewed as preliminary; although they are of magnitude similar to those obtained from model studies of the Arikaree aquifer in the Dwyer area adjacent to and north of the present study area (Lines, 1976; Hoxie, 1977).

Potentiometric Surface

The water table in an unconfined aquifer is that surface below which openings within the aquifer are completely filled with water and on which the pressure within the water-filled openings is atmospheric. The water table is assumed to define the distribution of hydraulic head, or the potentiometric surface, appropriate for the mathematical analysis of ground-water flow within the aquifer. The rate and direction of ground-water flow at a point within the aquifer is determined by the hydraulic conductivity and the slope of the plane tangent to the potentiometric surface at that point. The overall configuration of the potentiometric surface is determined by the distribution of transmissivity of the aquifer, the distribution of hydraulic head on the aquifer boundaries, and the rates and areal distribution of recharge to and discharge from the aquifer.

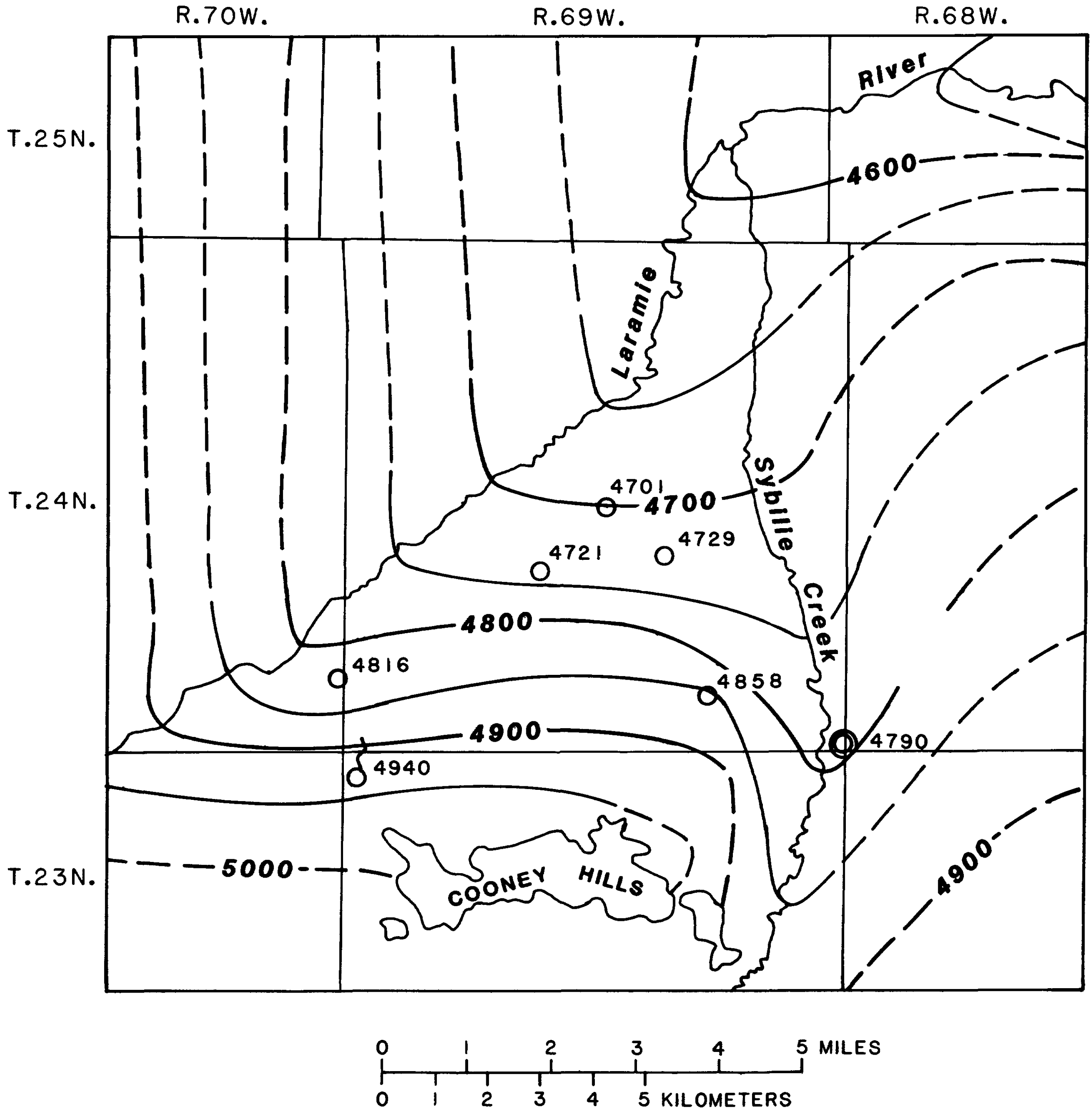
The configuration of the water table for the Arikaree aquifer in the vicinity of Muleshoe Flat is shown in figure 3. The water table was defined by water-level measurements in six wells (fig. 3), by the altitude of a spring (fig. 3), and by the altitude of the streambeds of the Laramie River and Sybille Creek. Water-table contours in the area outside of Muleshoe Flat were approximated by extrapolating from water-table maps prepared by Weeks (1964) for the Wheatland Flats area east of Sybille Creek and by Lines (1976) and Hoxie (1977) for the area north of the Laramie River.

Saturated Thickness

Because no deep water wells have been drilled in or near Muleshoe Flat, the thickness of the unconfined aquifer is not known. If rocks of the Oligocene White River Group are present beneath the Arikaree aquifer and are similar in lithology to equivalent rocks in adjacent areas (Morris and Babcock, 1960; Lines, 1976; and Hoxie, 1977), they are expected to be largely impermeable and to define the base of the unconfined aquifer system. Oil-test wells in secs. 10 and 21, T. 24 N., R. 69 W. both penetrated artesian-aquifer zones that flowed water at land surface. These zones occurred at depths greater than 600 feet, implying a shallower depth for the base of the unconfined zone. Because more refined data were lacking, a uniform thickness of 600 feet was assigned to the saturated thickness of the Arikaree aquifer in the study area.

Hydraulic Conductivity

Hydraulic conductivity is a parameter that measures the ability of an aquifer to transmit water. It is defined to be the volume of water transmitted per unit time through unit cross-sectional area under unit hydraulic gradient. Because no direct information was available, it was assumed that hydraulic conductivity values for the unconfined aquifer in Muleshoe Flat are similar to those found for the Arikaree aquifer in Wheatland Flats by Weeks (1964) and in the area north of Muleshoe Flat by Lines (1976) and Hoxie (1977). The hydraulic-conductivity distribution within the study area was determined implicitly during development of a steady-state ground-water-flow model for the aquifer system. The transmissivity distribution was obtained as the product of the hydraulic conductivity at each point with the assumed constant value of saturated thickness.



EXPLANATION

—— 5000 — — WATER-TABLE CONTOUR--Shows altitude of water table, November 1977. Contour interval 50 feet. Dashed where approximate. National Geodetic Vertical Datum of 1929 (NGVD Of 1929)

○ 4858 STOCK WELL SHOWING ALTITUDE OF WATER TABLE, IN FEET

◎ 4790 IRRIGATION WELL SHOWING ALTITUDE OF WATER TABLE, IN FEET

○ 4940 SPRING SHOWING ALTITUDE OF LAND SURFACE, IN FEET

Altitudes are above NGVD of 1929 for wells and spring

Figure 3.--Generalized configuration of the water table.

Specific Yield

Specific yield is a measure of the amount of water that is taken into or released from storage in an unconfined aquifer as a result of a rise or fall of the water table. It is defined as the volume of water that is released by gravity drainage per unit volume of saturated aquifer. The specific yield for the Arikaree aquifer in Muleshoe Flat was not determined as part of this study. A value of 0.12 was assumed for the specific yield based on determinations for the Arikaree aquifer in Wheatland Flats by Weeks (1964) and in the area north of Muleshoe Flat by Lines (1976).

Recharge and Discharge

Recharge to the Arikaree aquifer in Muleshoe Flat occurs from infiltration of precipitation within the area and from infiltration of surface runoff from the Cooney Hills. Ground water discharges from the aquifer to the Laramie River and Sybille Creek. Streamflow measurements made in November 1977 indicated a net gain of 2 ft^3/s to the Laramie River and 1 ft^3/s to Sybille Creek along the borders of Muleshoe Flat. Because the water-table gradient is assumed to be approximately the same on both sides of Sybille Creek and the Laramie River (fig. 3), it is assumed that ground water discharges to these streams at equal rates from the Arikaree aquifer on both sides of these streams. Under these assumptions the net rate of ground-water discharge to streams from the Arikaree aquifer in Muleshoe Flat is 1.5 ft^3/s. It is further assumed that this net rate of ground-water discharge is equal to the net rate of recharge and that recharge is distributed uniformly over the surface of Muleshoe Flat. This yields a net recharge rate of 0.04 $(ft^3/s)/mi^2$, which agrees well with the value of 0.06 $(ft^3/s)/mi^2$ that Lines (1976) estimated for the Arikaree aquifer in the area north of the Laramie River.

ANALYSIS

A digital model of the ground-water-flow system in Muleshoe Flat was constructed in order to assess the effects on both ground-water levels and streamflows to be expected from the proposed irrigation pumpage. Because the proposed irrigation wells would probably have to penetrate and be open to the full saturated thickness of the aquifer in order to obtain the desired yields, it follows that the overall ground-water-flow system may be properly approximated as two-dimensional. The model simulates the flow system mathematically and solves the resulting two-dimensional, time-dependent ground-water-flow equation numerically using finite-difference techniques. The computer code of Trescott and others (1976) as modified by Hoxie (1977) was employed in this analysis.

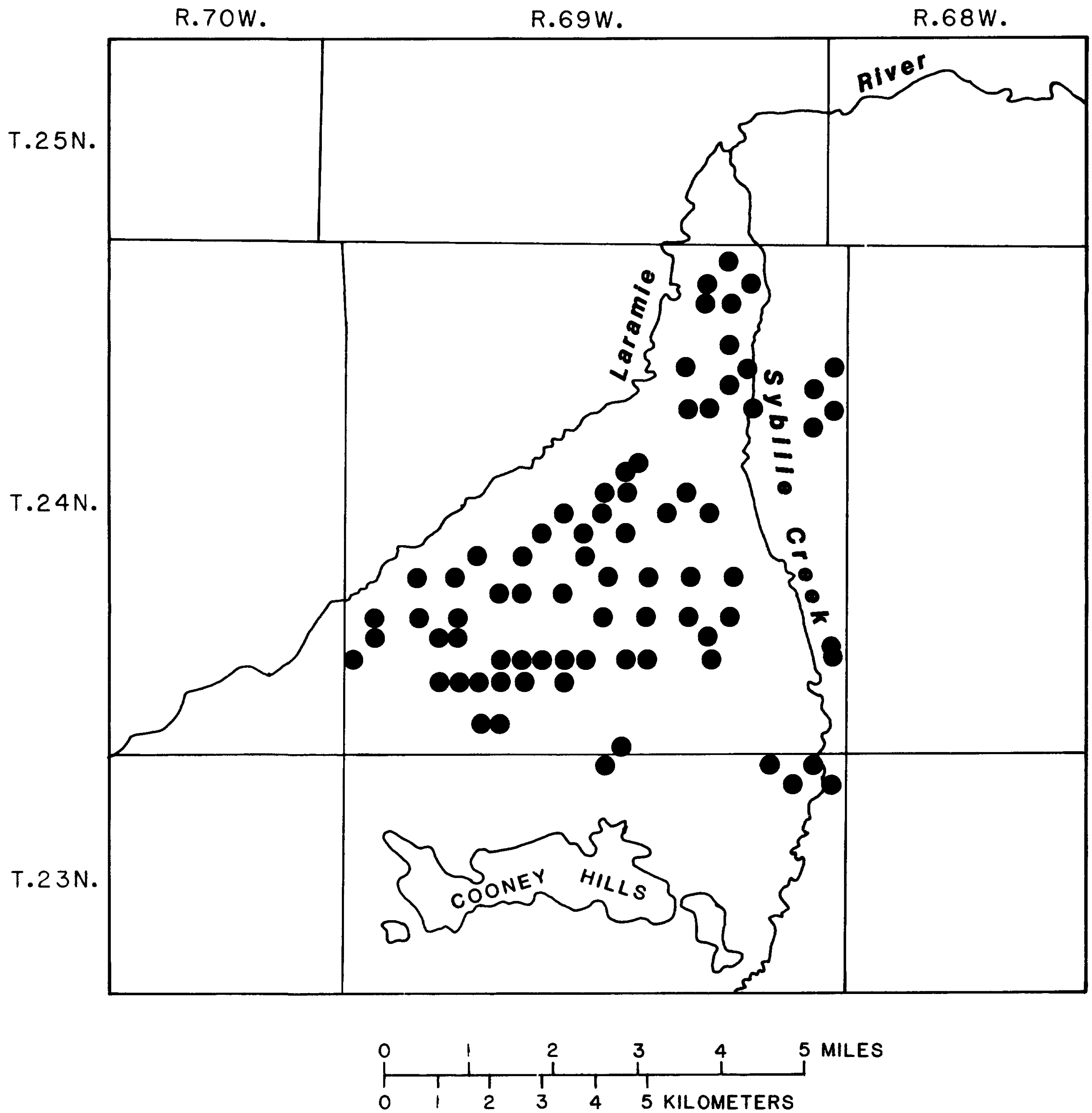
The spatial boundaries of the digital model are those of the study area shown in figure 1. These boundaries were treated as time-dependent flux boundaries wherein the initial flux (volume of water flowing through unit area per unit time) across the boundaries was calculated from the water-table gradients at the boundaries (fig. 3) and the adopted transmissivity distribution. The boundaries were placed sufficiently distant from the sites of the proposed irrigation wells to minimize effects attributal to the presence of these boundaries.

The interaction between the ground-water-flow system and surface streams was treated by means of the streamflow accounting procedure developed by Hoxie (1977). This procedure allows for time-dependent as well as spatially dependent hydraulic connection between aquifer and streams along stream reaches within the model area. Where flow is calculated to be present in a stream, the head in the stream was set to be 1 foot above the altitude of the streambed. In addition, the thickness of the streambed was set at 1 foot. Because direct information pertaining to streams bordering Muleshoe Flat was lacking, the vertical hydraulic conductivity of the streambeds was set uniformly at 2.7 ft/d, a value found by Moore and Jenkins (1966) for a reach of the Arkansas River in Colorado.

The digital model employed a finite-difference grid with a grid spacing of 2,640 feet. Construction of the model proceeded by first simulating the presumed equilibrium state of the system that was defined by ground-water-level and streamflow measurements in November 1977. It was assumed that the only outflow from the system was the measured ground-water discharge to the Laramie River and Sybille Creek and that this discharge was supplied by a uniformly distributed rate of recharge over the surface of Muleshoe Flat. This effectively steady-state system was simulated by adjusting the hydraulic-conductivity distribution that was input to model until the head distribution calculated by the model agreed with the observed water-table configuration (fig. 3) to within 15 feet at the center of each finite-difference cell. The resulting calibrated model supplied the initial conditions on which the proposed irrigation pumpage was imposed to generate a series of transient simulations.

The proposed annual irrigation pumpage of 12,480 acre-feet was distributed equally among the 76 proposed irrigation wells (fig. 4) and imposed on the model to generate the results shown in figures 5, 6, 7, and 8. The predicted water-level declines within the modeled area are shown at the end of 10 years (fig. 5), 20 years (fig. 6), and 40 years (fig. 7) of pumping. The predicted streamflow depletions in the Laramie River and Sybille Creek are shown in figure 8. Although it was assumed that all the wells were being pumped at their assigned annual average rates throughout the total 40-year period, the water-level declines that were predicted to occur at the end of 20 years suggest that the production rates of some wells probably could not be sustained. By the end of the 40-year period, approximately 22 of the 76 wells could be expected to experience yield reductions of greater than 50 percent.

The reduction in streamflows in the Laramie River and Sybille Creek that is estimated to be caused by proposed pumping in Muleshoe Flat is shown in figure 8. At the end of a 40-year simulation period, approximately 70 percent of the water withdrawn by the irrigation wells was predicted to be derived from net streamflow reductions of 4,300 acre-ft/yr in the Laramie River and of 4,700 acre-ft/yr in Sybille Creek. These reductions include (1) the interception of ground water that otherwise would have discharged to the streams and (2) the direct infiltration of surface flow from the streams to the aquifer. These results presume that surface flows in the streams will be sufficient to supply the calculated infiltration rates.



EXPLANATION

● PROPOSED SITE OF IRRIGATION WELL

Figure 4.--Locations of proposed irrigation wells.

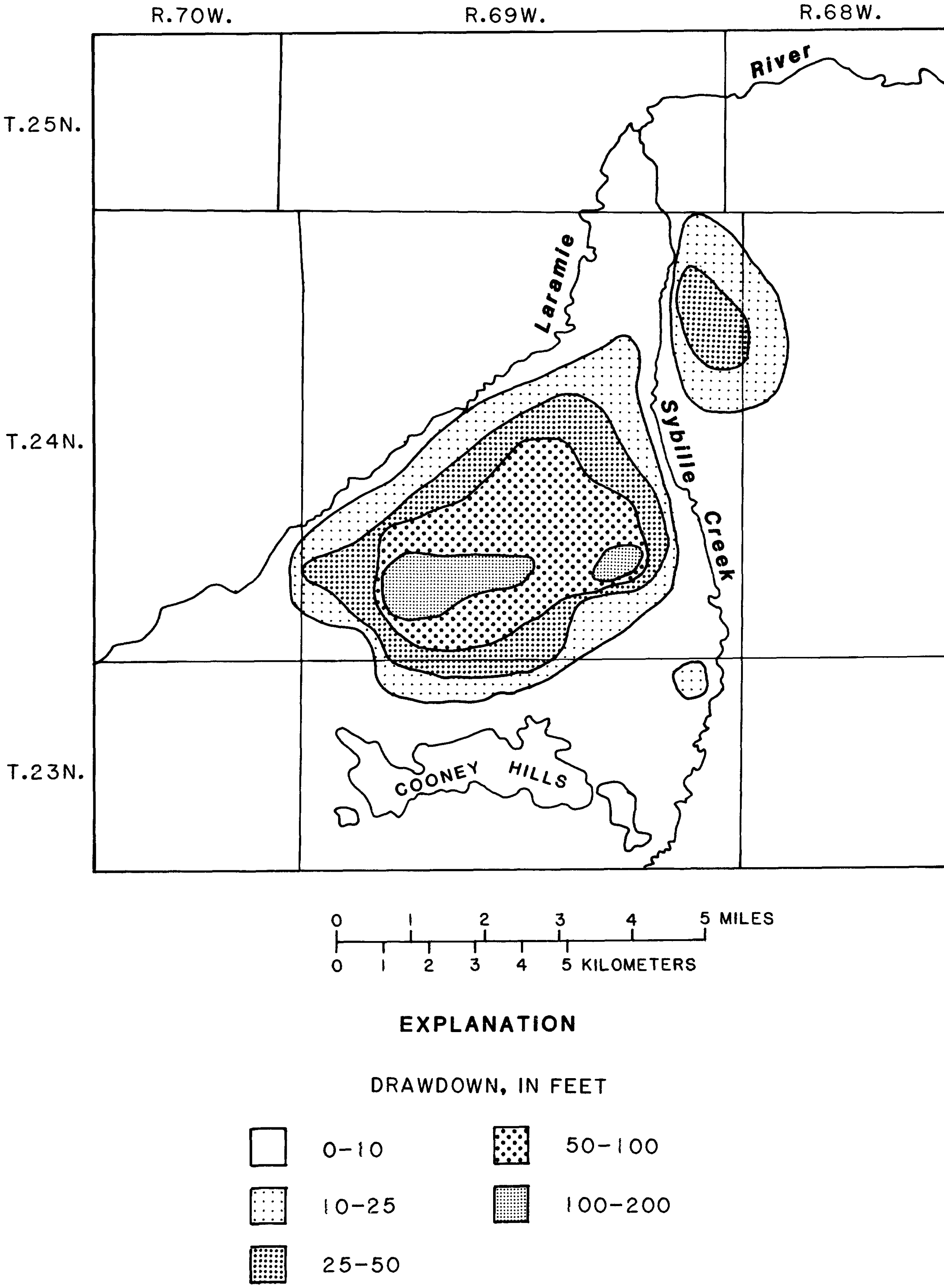
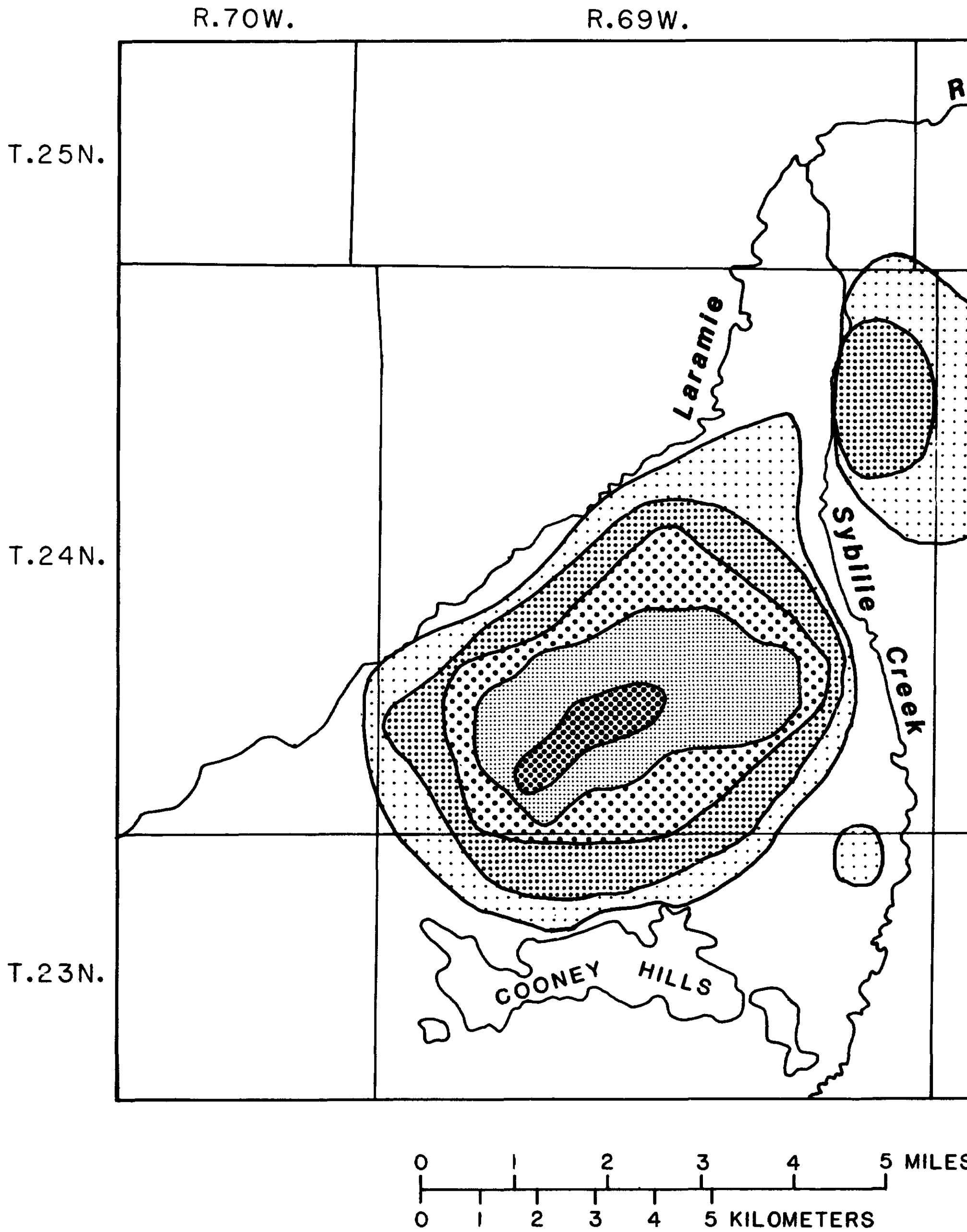


Figure 5.--Predicted drawdown distribution at the end of a 10-year simulation period.



EXPLANATION

DRAWDOWN, IN FEET

0-10

10-25

25-50

50-100

100-200

more than 200

Figure 6.--Predicted drawdown distribution at the end of a 20-year simulation period.

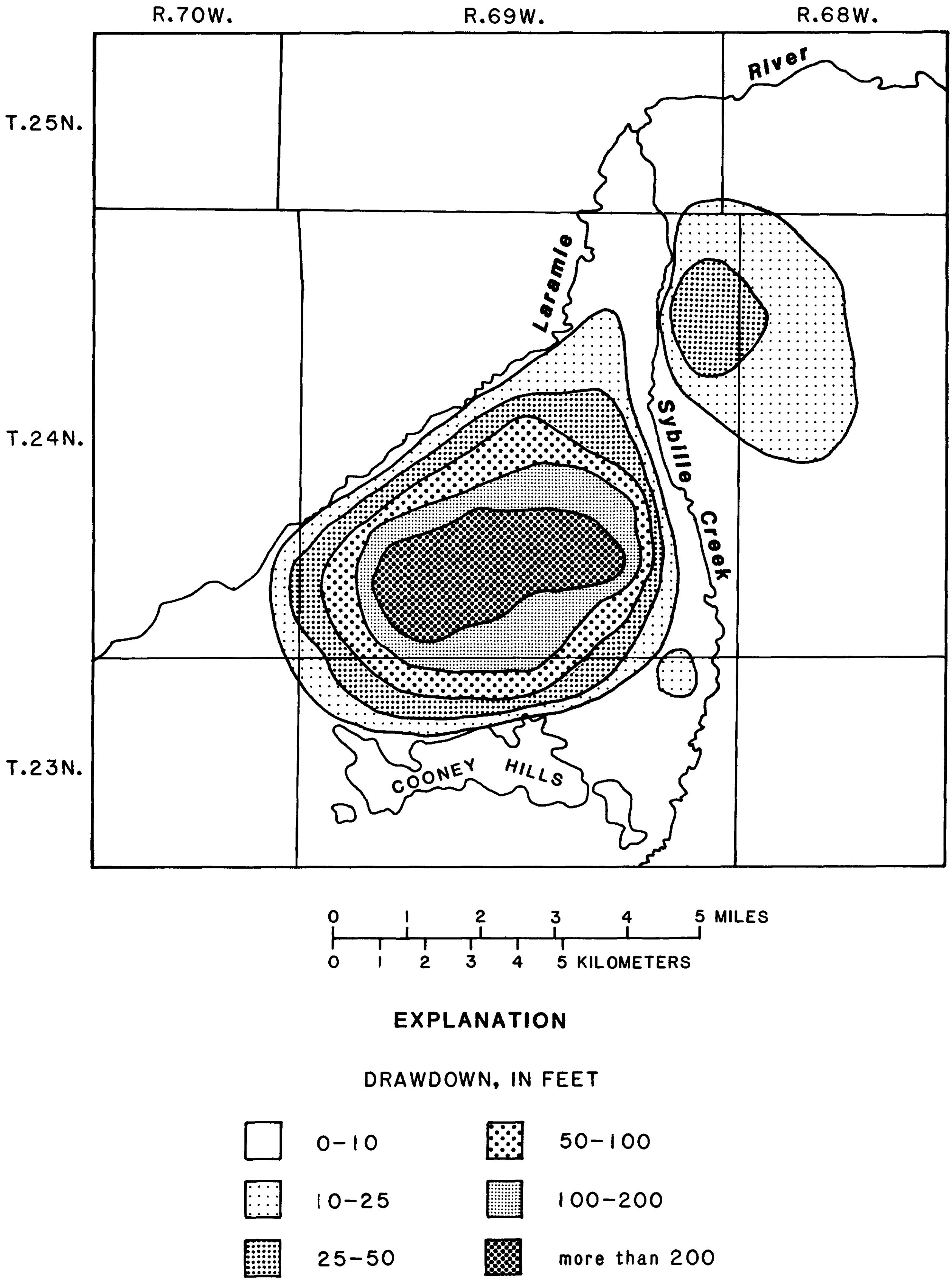


Figure 7.--Predicted drawdown distribution at the end of a 40-year simulation period.

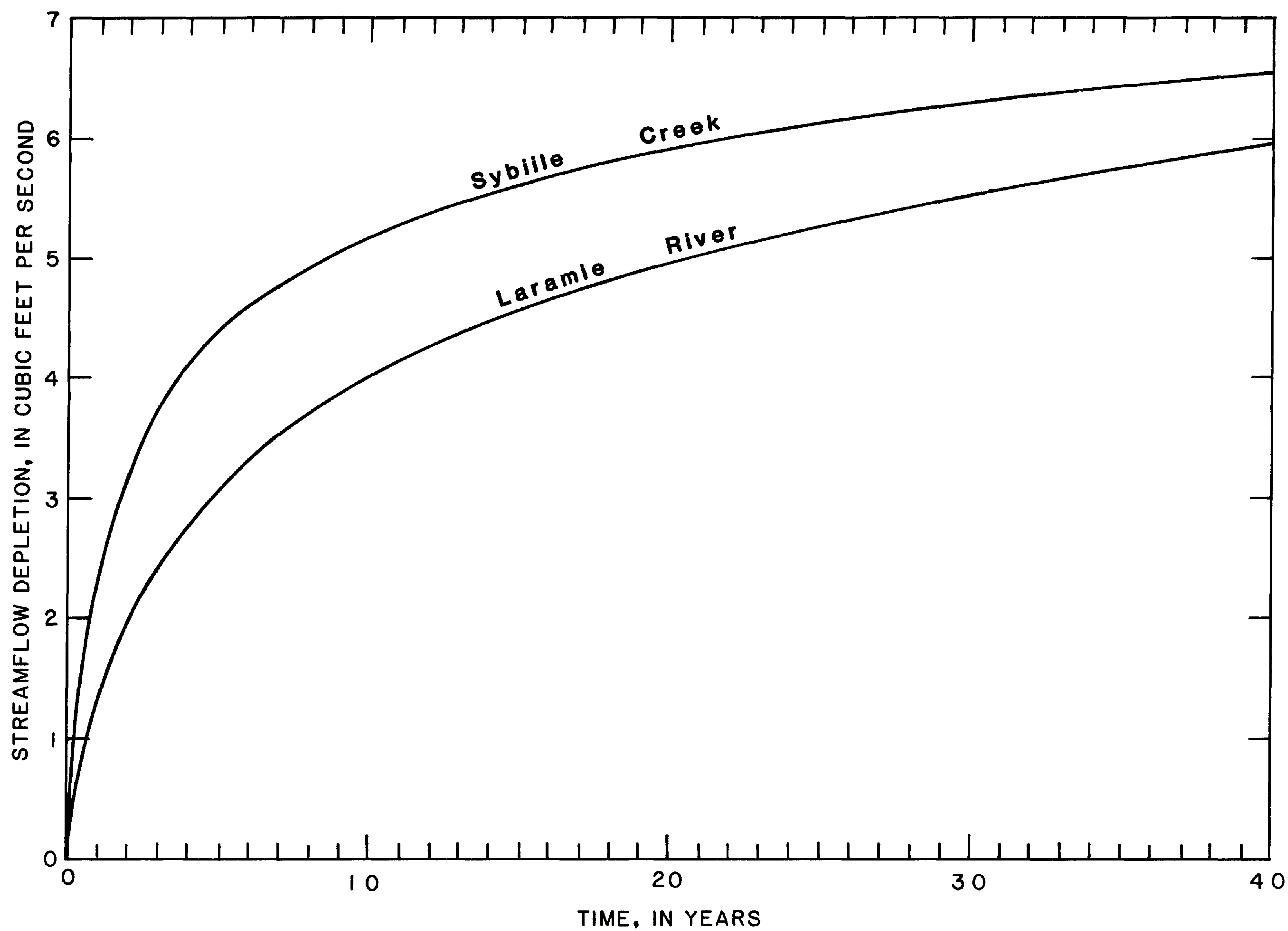


Figure 8.--Predicted streamflow depletions in the Laramie River and Sybille Creek.

ADDITIONAL DATA REQUIREMENTS

Because hydrologic data pertaining directly to the study area are lacking, assumed and extrapolated data were employed to construct the digital model of the flow system. To improve the reliability of the specific predictions, it would be necessary to collect additional field data. The data-collection program should include more streamflow measurements to refine the base-flow gains and losses to the Laramie River and Sybille Creek as well as drilling and testing to define the aquifer properties. Wells that penetrate the full thickness of the Tertiary deposits would be needed to delimit the unconfined aquifer zone and to determine the nature of the confined zone encountered by the oil-test wells in secs. 10 and 21, T. 24 N., R. 69 W. A test well and associated observation wells would need to be completed within the unconfined aquifer zone near one of the streams. Long-term aquifer tests of this well would be necessary to determine the degree of connection between the streams and the underlying aquifer. This type of testing would be needed in order to make a proper assessment of the streamflow depletions that may be caused by the proposed irrigation pumpage. Once these data were collected, the digital model could be refined in order to provide an improved assessment of the effects of the proposed irrigation development.

SUMMARY

The hydrologic effects of irrigating 8,320 acres of land in Muleshoe Flat from 76 proposed wells were assessed by constructing a digital ground-water-flow model based mainly on assumed and extrapolated data. Results of the model indicate that, at the end of a hypothetical 40-year pumping period, ground-water-level declines of more than 50 feet could be expected in an area of 12.5 mi^2 and of more than 200 feet in an area of 7 mi^2. Streamflow depletions of 4,300 acre-ft/yr could be expected in the Laramie River and 4,700 acre-ft/yr in Sybille Creek.

Additional data would refine and improve the reliability of the model predictions. These data should include streamflow measurements, drilling of test wells, and aquifer tests.

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