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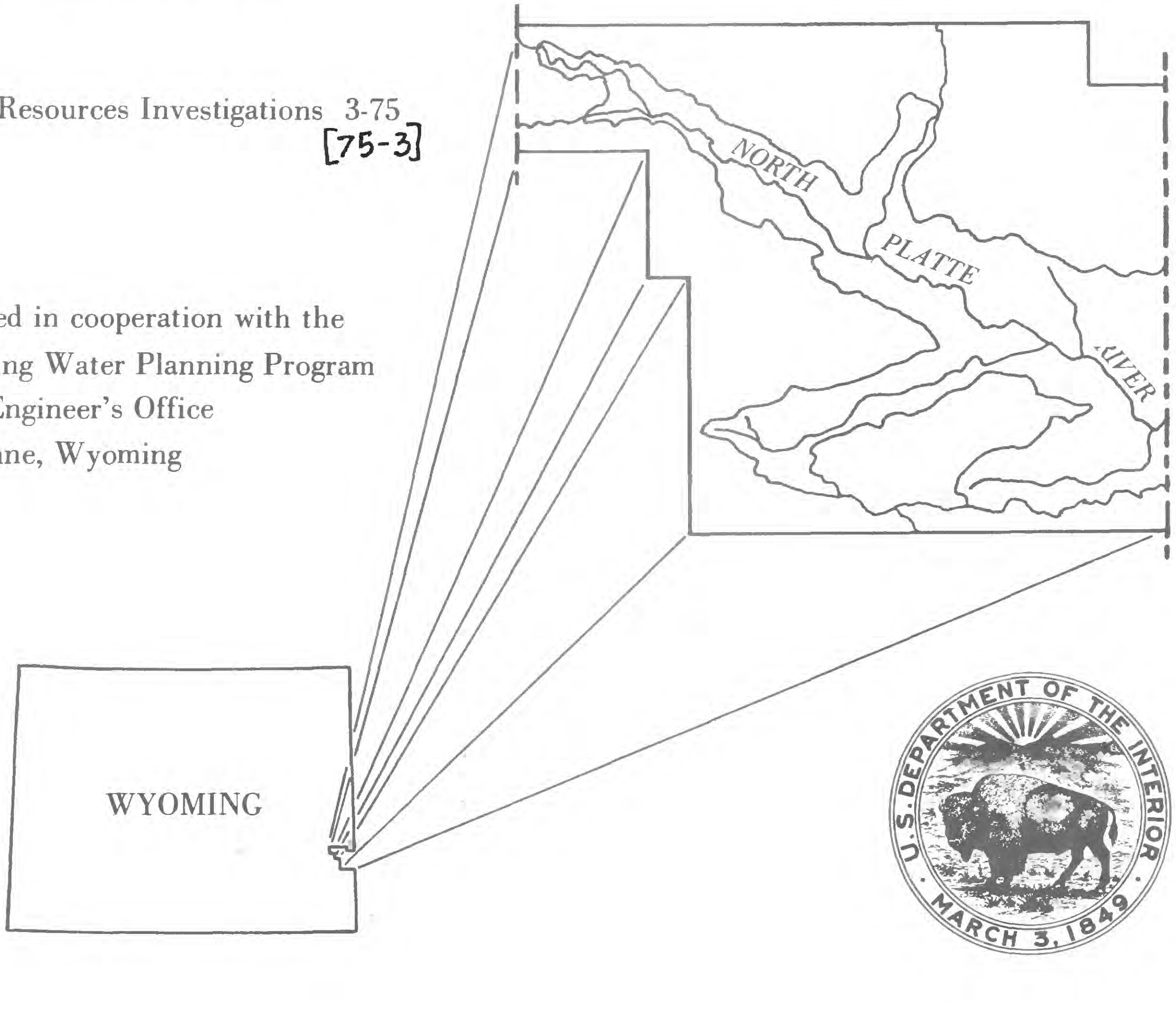
HYDROLOGIC ANALYSIS OF THE VALLEY-FILL AQUIFER, NORTH PLATTE RIVER VALLEY, GOSHEN COUNTY, WYOMING

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 3-75
[75-3]

Prepared in cooperation with the
Wyoming Water Planning Program
State Engineer's Office
Cheyenne, Wyoming



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The North Platte River valley is a highly productive agricultural area where most crops are irrigated principally with surface water. More than 200 irrigation wel in the valley fill are pumped for supplemental irrigation supplies. Ground water in storage in the valley fill is estimated to be about 1.7×10^6 acre-feet ($2.1 \times 10^9 m^3$).

Recharge to ground water in the valley fill from precipitation and imported irrig tion water amounted to about 73,000 acre-feet ($90 \times 10^6 m^3$) and is nearly equal to the 76,000 acre-feet ($94 \times 10^6 m^3$) estimated as the amount of ground water contributed to t North Platte River during the 1-year study.

The hydrologic system of the valley fill is simulated with a digital model. Month net head change in the aquifer and the monthly net change in the ground-water discharg to the North Platte River was used to calibrate the model. The digital model develope during this investigation can be used to predict the effect of change in stress that might be applied to the system.

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CONTENTS

	Page
Abstract	1
Introduction	2
Purpose and scope	3
Location and climate of the area	4
Previous investigations	4
Method of investigation	4
Well-numbering system	6
Acknowledgments	6
Hydrologic system	8
Ground water	10
Geologic units and their water-bearing properties	10
Potentiometric surface	12
Storage	14
Surface water	14
Quality of water	15
Water budget	15
Inflow	15
Streams	20
Precipitation	20
Irrigation	27
Underflow	28
Outflow	28
Surface flow	28
Underflow	28
Evapotranspiration	33
Pumpage	33
Summary of water budget	36
Digital model	44
Conclusions	56
References cited	58

ILLUSTRATIONS

		Page
Figure 1.	Index map of Wyoming showing the location of the area described in this report-------------------------	5
2.	Diagram showing the system of numbering wells-----------	7
3.	Schematic diagram of the surface-water distribution system--	9
4.	Rectangular grid used to model the valley fill----------	45
5.	Graph of estimated monthly net change in altitude of the water level in "stream cells"---------------------	48
6.	Map showing estimated hydraulic conductivity of the valley fill based on aquifer tests--------------------	50
7.	Map showing hydraulic conductivity used during calibration of the digital model---------------------	51
8.	Graph of monthly net ground-water discharge to the North Platte River between Whalen Dam and the Wyoming-Nebraska State line--------------------------	53
9.	Map showing model water-level changes predicted for the second year after sealing the Interstate Canal--	54
10.	Graph showing results of two conditions simulated in the digital model---------------------------------	55
11.	Map showing model water-level changes predicted for the second year of maintaining water in the Interstate Canal during the nonirrigation season------	57

TABLES

		Page
Table 1.	Chemical analyses of water	16
2.	Estimated runoff and recharge to the modeled area from precipitation	22
3.	Estimated consumptive irrigation requirement for 1970	24
4.	Estimated distribution of canal diversions during 1970	25
5.	Estimated distribution of losses from the Interstate Canal in 1970	29
6.	Estimated diversions and distribution of losses from the Fort Laramie Canal in 1970	30
7.	Underflow into the system through sand and gravel deposits along the North Platte River, Laramie River, and Rawhide Creek	32
8.	Underflow out of the system at the Wyoming-Nebraska State line	32
9.	Estimated pumpage from irrigation and municipal wells	34
10.	Water budget for the North Platte River in the modeled area	38
11.	Water budget for the system	40

PLATES

		Page
Plate 1.	Geologic map of the North Platte River valley, Goshen County, Wyoming	In pocket
2.	Hydrologic map of the North Platte River valley, Goshen County, Wyoming	In pocket
3.	Saturated thickness map of unconsolidated sand and gravel deposits in the North Platte River valley, Goshen County, Wyoming	In pocket
4.	Map of the transmissivity generated from saturated thickness and adjusted hydraulic conductivity of the valley fill in the North Platte River valley, Goshen County, Wyoming	In pocket

HYDROLOGIC ANALYSIS OF THE VALLEY-FILL AQUIFER, NORTH PLATTE RIVER VALLEY, GOSHEN COUNTY, WYOMING

By Marvin A. Crist

ABSTRACT

The North Platte River valley in Goshen County, Wyoming, is a highly productive agricultural area where most crops are irrigated principally with surface water. The Interstate Canal, the Fort Laramie Canal, and other smaller canals distribute surface water along both sides of the North Platte River. More than 200 irrigation wells, tapping the valley fill, are pumped for supplemental irrigation supplies.

The purpose of this investigation is to make a quantitative evaluation of ground water in the valley fill and surface water in the North Platte River valley. The area studied is about 35 miles (56.3 kilometres) long and ranges from 1 to about 6 miles (1.6 to 9.6 kilometres) wide along the North Platte River.

Ground water in storage in the valley fill is estimated to be about 1.7×10^6 acre-feet (2.1×10^9 cubic metres). Infiltration of irrigation water and seepage from canals cause the water level to rise in most of the study area during the irrigation season. Generally, the water level declines after the irrigation season.

No meaningful pattern of dissolved-solids concentration was ascertained from ground-water samples analyzed during this study. For the 30 ground-water samples, the mean dissolved-solids concentration was 615 milligrams per litre and the standard deviation was 128 milligrams per litre. Calcium and bicarbonate are the predominant cation and anion, respectively, in the streams entering the area. Calcium and sulfate are the predominant cation and anion, respectively, in the North Platte River at the point where the river leaves the study area.

Inflow in the form of recharge to ground water (from precipitation, seepage from canals, and seepage from surface-water irrigation) amounted to 72,540 acre-feet (89.4×10^6 cubic metres), which is nearly equal to the 76,320 acre-feet (94.1×10^6 cubic metres) estimated as the ground-water contribution to the North Platte River. It is assumed that no net change in storage occurred in the hydrologic system of the valley fill between April 1970 and March 1971 because water-level measurements in observation wells indicate little change in storage occurred in this period.

The digital model developed during this investigation can be used to predict the general effect of changes in stress that might be applied to the system. The model was calibrated on the basis of ground-water discharge to the North Platte River and water-table altitudes in observation wells. Application of the model indicates significant changes would occur in ground-water storage if leakage from the Interstate Canal was altered by (1) sealing the canal or (2) leaving water in the canal during the nonirrigation season.

INTRODUCTION

The North Platte River valley from Whalen Dam downstream to the Wyoming-Nebraska State line is a highly productive agricultural area as a result of irrigation. Principal source of the irrigation water is surface water diverted from the North Platte River. Additional irrigation water is pumped from wells in valley fill, which consists of unconsolidated clay, silt, sand, and gravel. Ground water pumped for irrigation is used to supplement the surface-water supplies.

Flow in the North Platte River is regulated by terms of a U.S. Supreme Court decree dated October 1945 and modified in 1952. Article V in the decree states, in part: "The natural flow in the Guernsey Dam to Tri-State Dam section between and including May 1 and September 30 of each year, including the contribution of Spring Creek, be and the same hereby is apportioned between Wyoming and Nebraska on the basis of twenty-five percent to Wyoming and seventy-five percent to Nebraska, * * * ". Guernsey Dam is about 7 miles (11.3 km) upstream from Whalen Dam and Tri-State Dam is about 0.5 mile (0.8 km) east of the State line. Natural flow water is defined in the decree, " * * * as referring to all water in the stream except storage water;". Storage water is defined in the decree as, "* * * any water which is released from reservoirs * * *". All reservoirs referred to are located outside the area of this study.

For those readers interested in using the metric system, metric equivalents of English units of measurement are given in parentheses. The following table may be used to convert the English units of measurement used in this report to metric units:

Acres	x	4,047	= Square metres (m^2)
Acre-feet	x	1,233	= Cubic metres (m^3)
Cubic feet (ft^3)	x	.02832	= Cubic metres (m^3)
Square feet (ft^2)	x	.0929	= Square metres (m^2)
Inches (in)	x	25.4	= Millimetres (mm)
Feet (ft)	x	.3048	= Metres (m)
Gallons per minute (gal/min)	x	.00006309	= Cubic metres per second (m^3/s)
Miles (mi)	x	1.6093	= Kilometres (km)
Square miles (mi^2)	x	2.59	= Square kilometres (km^2)
Cubic feet per day per square foot [(ft^3/d)/ft^2]	x	.000003528	= Cubic metres per second per square metre [(m^3/s)/m^2] After unit cancellation = metre per second (m/s)
Cubic feet per day per foot [(ft^3/d)/ft]	x	.0929	= Cubic metres per day per metre [(m^3/d)/m]
Cubic feet per second (ft^3/sec)	x	.02832	= Cubic metres per second (m^3/sec)
Feet per mile (ft/mi)	x	.1894	= Metres per kilometres (m/km)
Feet per day (ft/d)	x	.3048	= Metres per day (m/d)

Purpose and Scope

In recent years, the increasing number of irrigation wells has raised a question regarding the interrelationship between ground and surface water in the valley. A study was needed to investigate effects of surface-water irrigation and pumping of ground water on the flow in the North Platte River.

Initially, this study was planned to collect basic data to be used in the construction of a model. Herrmann (1972) used much of the basic data in the preparation of a thesis on the relation of shallow aquifers and surface water in the North Platte River valley. He prepared a digital model for the area; however, the model was not suitable for the State Engineer to use as a guide for administration of water rights in the valley. As a result, this study was expanded in 1972 to include a digital model. The model was prepared with sufficient provisions in the computer program to enable water-rights administrators to use the model as a tool to predict effects of any new stress changes that might be proposed for the hydrologic system.

The purpose of this investigation is to make a quantitative evaluation of ground water in the unconsolidated sand and gravel deposits in the valley fill and surface water in the North Platte River valley in Goshen County. This report describes the hydrologic system and includes water budgets for the system and for the North Platte River.

Location and Climate of the Area

The area is about 35 miles (56.3 km) long and ranges from about 1 to 6 miles (1.6 to 9.7 km) wide along the North Platte River between Whalen Dam and the Wyoming-Nebraska State line. The area is in Goshen County, Wyoming (fig. 1).

The climate is typical of the northern High Plains, characterized by low precipitation, high rate of evaporation, and a wide range in temperature. Normal precipitation at Torrington is 13.52 inches (343 mm), about half of which occurs during April, May, and June. The mean annual temperature is 48.2°F (9°Celsius) and the length of the growing season is about 150 days.

Previous Investigations

Adams (1902); Smith (1903); Darton (1903); Veatch and McClure (1921); Schlaikjer (1935a, b, and c); and Wenzel, Cady, and Waite (1946) prepared reports on the geology and water resources in the area of this investigation and adjacent areas. Visher and Babcock (1953) made a ground-water study in an area several miles southwest of Torrington. Visher, Rapp, and Babcock (1954) prepared an open-file report on the geology and ground-water resources of the North Platte Irrigation Project in Goshen County. Data from this latter report is incorporated in Rapp and others (1957).

Method of Investigation

The inventory of wells used for irrigation, industry, and municipal supplies was updated in 1972. Annual pumpage from these wells was estimated from power records for each year from 1969 through 1972.

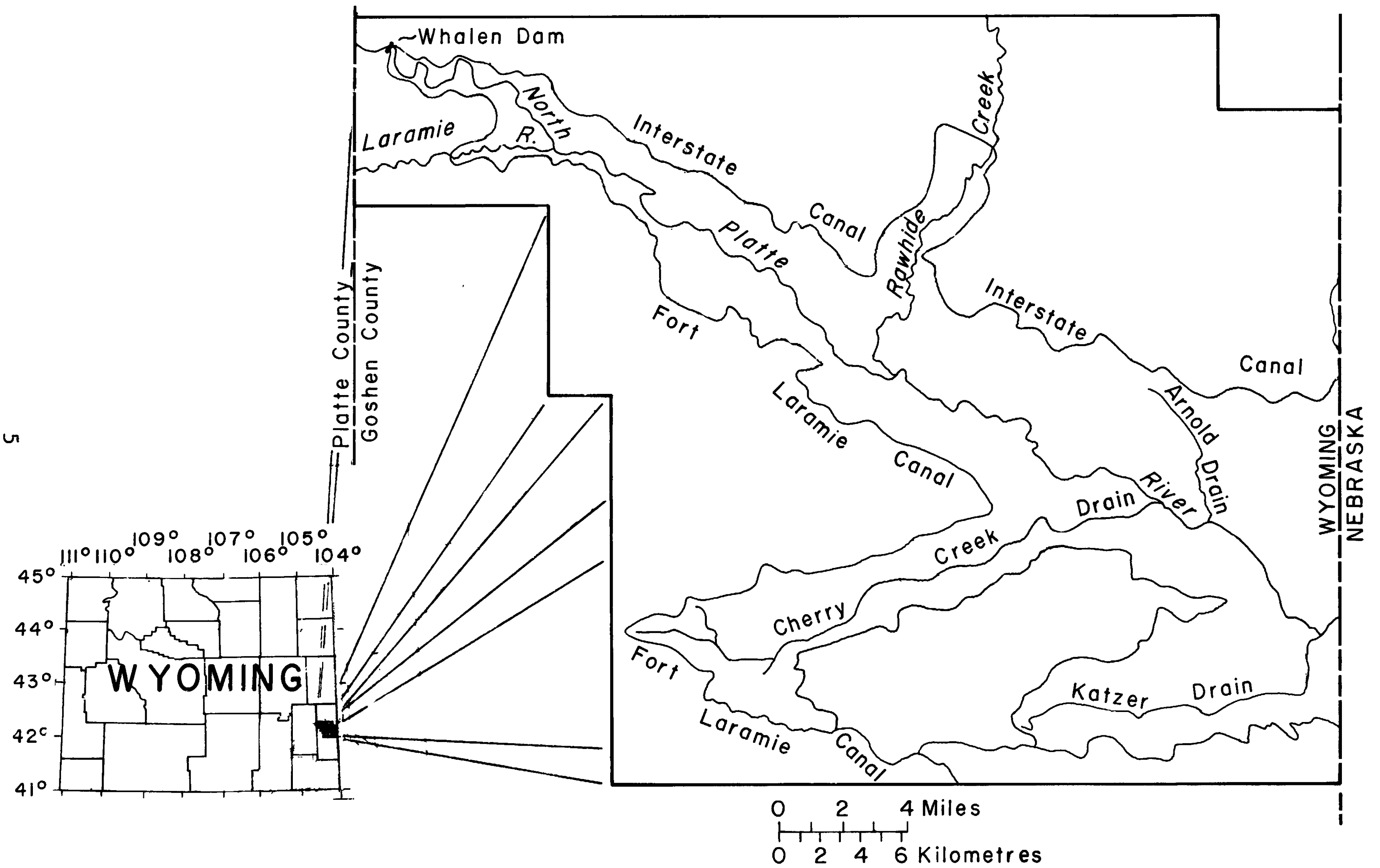

Figure 1.--Location of the area described in this report.

An inventory was made of all surface water entering and leaving the area. This included natural streamflow plus surface water used for irrigation.

A network of 38 observation wells was used to observe water-level fluctuations. Water levels were measured monthly in these wells from August 1969 through September 1972.

Geologic and hydrologic data were compiled to describe the hydrologic system. Data from Rapp and others (1957), plus well logs obtained in recent years, were used in constructing a contour map showing the configuration of the bedrock surface underlying the valley fill. A map showing the saturated thickness of the valley fill was also constructed. These data were used to develop a digital model of the hydrologic system in the valley fill.

Chemical analyses were made of 4 surface-water samples and 30 ground-water samples. Most of the ground-water samples were from wells in the valley fill.

Well-Numering System

Wells cited in this report are numbered according to the Federal System of land subdivision in Wyoming (fig. 2). 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) ($4.05 \times 10^4 m^2$). 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 ($4.05 \times 10^4 m^2$) tract, consecutive numbers starting with 1 follow the lowercase letter of the well number. If a section does not measure 1-mile square (about 1.6 km^2), 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 wishes to express his appreciation for the cooperation he received while working in the area. Many well owners supplied information about their wells and gave permission for measurement of water levels and well discharge. Wyrulec Company, Kansas-Nebraska Natural Gas Company, Inc., and the city of Torrington permitted examination of power-consumption records for irrigation and municipal wells. The management of Pathfinder Irrigation District and Goshen Irrigation District permitted access to records of irrigation in the area.

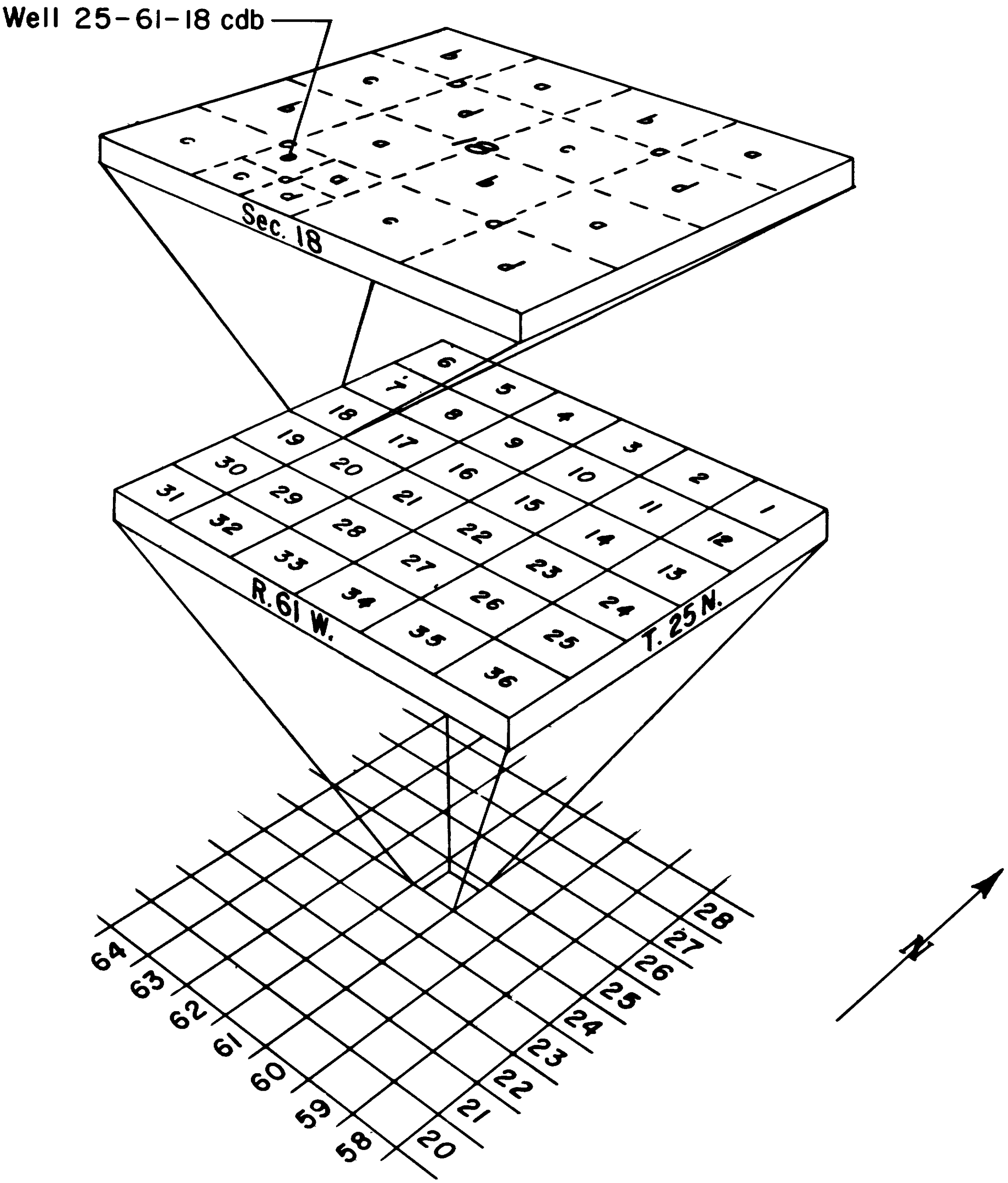

Figure 2.--System of numbering wells

William C. Borchert, of the U.S. Geological Survey, assisted in making aquifer tests, water-level measurements in observation wells, and measurement of Interstate Canal discharge. Raymond Herrmann, a graduate student at the University of Wyoming, helped in the mass water-level measurements.

Special thanks are extended to Leonard Konikow and John Bredehoeft, of the U.S. Geological Survey, for their help and advice in setting up the digital model.

HYDROLOGIC SYSTEM

Ground water and surface water are interrelated in a stream-aquifer system. When wells are pumped, the water is obtained from three major sources (1) the stream, (2) ground-water storage, and (3) salvaged evapotranspiration. In this area, streams are in hydraulic connection with the valley fill. The soils of the valley fill are irrigated by surface water diverted from streams and ground water pumped from wells in the valley fill. Part of the applied irrigation water is lost to evapotranspiration. Water that is not lost provides recharge to the ground water and return flow to the streams. Precipitation that falls in the area adds to the total amount of water in the area. A water budget listing the breakdown of inflow and outflow is one method of illustrating the relation of ground water to surface water in a stream-aquifer system.

This report describes the hydrologic system of the valley fill. The areal extent of the valley-fill hydrologic system is shown in the schematic diagram (fig. 3). All water entering and leaving this area, whether by streams, canals, underflow, evapotranspiration, or precipitation, influences the amount of ground water in storage.

A model was developed for this system that comprises an area of about 140 square miles (362.6 km^2) of valley fill on both sides of the North Platte River. This area is irrigated primarily with surface water transported through a network of canals.

Most of the irrigation water is diverted at Whalen Dam into the Interstate and Fort Laramie Canals. Other smaller canals downstream from Whalen Dam also divert water from the river. The irrigation water is stored in reservoirs upstream from the modeled area and released as needed.

Between the two major canals, ground water is pumped to supplement surface-water supplies for irrigation; however, north of the Interstate Canal and east of Rawhide Creek, ground water is the principal source of irrigation water.

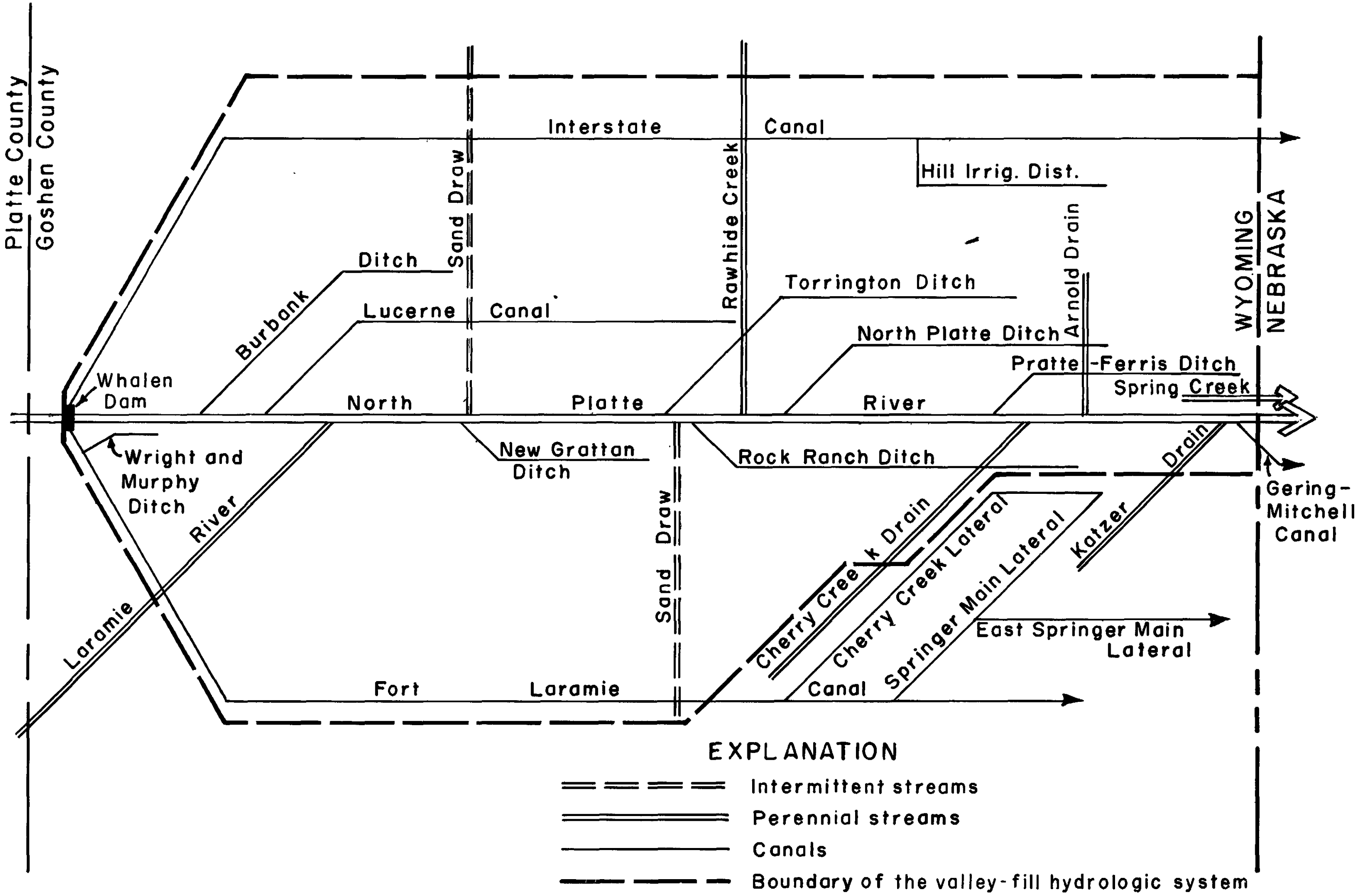

Figure 3 --Schematic diagram of the surface water distribution system.

Much of the recharge to ground water in the valley fill is derived from seepage from canals and surface-water irrigation. Lesser amounts of recharge are received from precipitation and by underflow primarily through the alluvium along the North Platte and Laramie Rivers and along Rawhide Creek.

Most of the ground-water recharge from irrigation drains to the North Platte River and leaves the area as surface water. Some of the ground water leaves the area as underflow through the valley fill.

Ground Water

This investigation is concerned primarily with the unconsolidated deposits of the valley fill overlying the consolidated bedrock formations. The only consideration given to the bedrock aquifers, beyond a brief summary, is to determine if the water in those aquifers has any distinguishable influence on the quantity and quality of the water in the unconsolidated sand and gravel deposits.

Ground water in the study area is derived from underflow, infiltration of irrigation water, seepage from canals, and precipitation. All the perennial streams in the study area are in contact with the water table; therefore, there is an exchange of water between the streams and the ground-water reservoir. Water-table conditions exist in the unconsolidated aquifers and are assumed to exist in the bedrock aquifers; therefore, the water table is considered to be continuous throughout the study area.

Geologic Units and their Water-Bearing Properties

All the geologic formations exposed in the area (pl. 1) yield water to wells. These formations have been described by Rapp and others (1957) but, because their report is out of print, condensed descriptions of aquifers from their report are repeated here.

The oldest formation exposed in the area is the Lance Formation of Late Cretaceous age. Rapp and others (1957) describe two distinctive units in the formation--a lower unit and an upper unit. The lower unit is a thick sequence of beds of shale, siltstone, and sandstone with some thin beds of coal. The upper unit consists of beds of sandstone and shale. Many stock and domestic wells produce water from this formation but no irrigation wells are known to be pumping water from the Lance. Mechanical analysis of particle-size distribution (Rapp and others, 1957, p. 28) indicates low permeability in the Lance Formation.

The Chadron Formation of the White River Group of Oligocene age overlies the Lance Formation. The lower part of the Chadron is the most permeable and consists of beds ranging in grain size from clay to very coarse gravel. The upper part consists mostly of silt with an admixture of clay and sand. Mechanical analysis of the grain size (Rapp and others, 1957, p. 30) shows that the largest percentage of material is silt size. In the area of this investigation, no large-capacity wells are known in the Chadron Formation.

The Brule Formation of the White River Group of Oligocene age overlies the Chadron Formation. The Brule consists mostly of hard siltstone. Grain-size analysis (Rapp and others, 1957, p. 33) shows that most of the material is silt and clay size. Babcock and Keech (1957, p. 4) reported the average hydraulic conductivity for the Brule and Chadron to be 0.003 and 0.0003 $(ft^3/d)/ft^2$ (1.06×10^{-8} and 1.06×10^{-9} m/s), respectively, from five samples analyzed. The term "hydraulic conductivity," in units of length and time, replaces the term "field coefficient of permeability," in units of gallons per day per square foot, used by Babcock and Keech.

Only one irrigation well in the study area is known to be completed in the Brule. The yield from this well (25-62-5ada) is reported to be about 300 gal/min ($1.9 \times 10^{-2} m^3/s$), which is low compared to other irrigation wells in the study area.

There is evidence of secondary permeability in the Brule Formation in other areas. Many irrigation wells are completed in the Brule Formation near La Grange, Wyo., about 30 miles (48.3 km) south of Torrington. Near Pine Bluffs, Wyo., about 70 miles (112.7 km) south of Torrington, where the Brule and Chadron Formations are undifferentiated, many irrigation wells produce water from the White River Formation of Oligocene age.

The Arikaree Formation of early Miocene age overlies the Brule Formation and consists mainly of very fine to fine-grained sandstone that contains beds of siltstone, layers of hard concretionary sandstone, and a few beds of volcanic ash. The formation contains a conglomerate in the basal part that ranges in grain size from very fine gravel to large boulders. The upper part of the formation consists mostly of massive fine-grained sandstone. Babcock and Keech (1957, p. 4) reported an average hydraulic conductivity of 5.35 $(ft^3/d)/ft^2$ (1.89×10^{-5} m/s) for five samples of Arikaree. Whitcomb (1965, p. 48) reported hydraulic conductivities ranging from about 4.0 to about 41.4 $(ft^3/d)/ft^2$ (1.41×10^{-5} to 1.46×10^{-4} m/s) determined from four aquifer tests in the Arikaree in Niobrara County. Storage coefficients of 0.0015 and 0.002 were determined from two of the aquifer tests.

The Ogallala Formation of late Miocene and Pliocene age, which overlies the Arikaree Formation, is exposed in only a few places along the northern part of the mapped area. The Ogallala consists of heterogeneous deposits of silt, sand, and gravel, which may be either unconsolidated or well cemented. Although the Ogallala is an important aquifer elsewhere, the formation is considered to have no hydrologic significance in this investigation because of the small areal extent of the formation in the report area.

Rapp and others (1957) mapped the Quaternary deposits as upland deposits, valley fill, and dune sand. The upland deposits of Pliocene(?) and Pleistocene age border the North Platte valley and consist of remnants of terrace deposits, pediment deposits, residuum from conglomerates, channel deposits, and river deposits, and include deposits of sand and gravel that underlie the upland slopes. Those deposits mapped by McGrew (1963 and 1967) as terrace deposits of Quaternary age are shown as upland deposits in this report.

The valley fill of Pleistocene and Holocene age consists mainly of permeable sand and gravel. The valley fill includes what Rapp and others (1957) describe as the third terrace, the second terrace, the first terrace, and the flood-plain deposits. The hydraulic conductivity computed from six aquifer tests (Rapp and others, 1957, p. 45) for the flood-plain deposits ranged from about 200 to about 1,200 $(ft^3/d)/ft^2$ (7.06×10^{-4} to 4.23×10^{-3} m/s) and for the third-terrace deposits ranged from about 300 to about 800 $(ft^3/d)/ft^2$ (1.06×10^{-3} to 2.82×10^{-3} m/s). They reported storage coefficients of 0.235 for the flood-plain deposits and 0.216 for the third-terrace deposits. No aquifer tests were made in the first- and second-terrace deposits.

Dune sand is mapped along the northeastern boundary of the study area. The dune sand generally lies above the water table and is not considered to be an aquifer in this investigation, although the sand serves as a significant recharge area.

Potentiometric Surface

Configuration.--A contour map was prepared (pl. 2) showing the configuration of the potentiometric surface (the surface which represents the static head of ground water) by measuring the depth to water in about 130 wells in April 1971. The map is representative of that period when the water levels are most stable. That is, water levels are not changing rapidly as a result of pumping or as a result of recharge from irrigation.

Some anomalies noted in the potentiometric surface, such as the "ground-water mound" in the south-central part of the map, are probably an indication of a perched water table. Elsewhere in the southeastern part of the map (pl. 2), perched water table occurs in much of the area as the result of upper zones being saturated by applied irrigation water. Control for contours in the extreme southeastern corner of the map (pl. 2) is the water level in wells, many small water-table lakes not shown, and Horse Creek. Most of Horse Creek and some of the wells are located to the south, outside the area shown in plate 2.

Generally, the ground water moves toward the streams; thence, generally eastward toward Nebraska. The direction of ground-water movement is approximately at right angles to the contours. The shape of the contours shows that Rawhide Creek is a gaining stream in the upper reach and a losing stream in the lower reach near the North Platte. The Laramie River and the North Platte River are generally gaining streams. Some sections of the North Platte River lose water to the valley fill, as indicated by the position of the contours.

Fluctuation.--Water levels change in response to an increase or decrease of water in storage in the ground-water reservoir; water in storage, in turn, is a function of the relative rates of recharge and discharge. Because of infiltration of irrigation water and seepage from canals and laterals, water levels generally rise during the irrigation season in those areas between the Interstate and the Fort Laramie Canals. East of Rawhide Creek and north of the Interstate Canal, the water levels decline during the irrigation season and rise after irrigation has ceased because ground water is the only utilized source of irrigation water in that area.

A network of 38 wells (one well in Nebraska is not shown on pl. 2) was established in August 1969 to observe water-level fluctuations. The water levels were measured monthly in these observation wells through September 1972, and the measurements through December 1971 are published (Ringen, 1973, p. 120-153). Fluctuations of the water level in observation wells ranged from less than 1 foot (0.3 m) to about 10 feet (3.0 m) with the average about 4.5 feet (1.4 m). The drawdown in a pumping well was not considered in the range of fluctuation, although drawdown in most irrigation wells, while pumping, ranges from about 10 to 20 feet (3.0-6.1 m).

Storage

Ground water in storage refers to the amount of water in the saturated part of the sand and gravel deposits. A map showing the saturated thickness of the valley fill (pl. 3) was constructed by overlaying the bedrock contour map (pl. 1) on the potentiometric map (pl. 2) and drawing lines through the points of equal difference in altitude. Ground water in storage in the valley fill (1971) was estimated to be about 1.7×10^6 acre-feet ($2.1 \times 10^9 m^3$). This was determined by multiplying the area between the lines of equal saturated thickness (pl. 3) by the estimated average saturated thickness and by a specific yield of 0.23 assumed for the entire area.

Surface Water

The principal streams in the study area are the North Platte River and its tributaries--the Laramie River, Rawhide Creek, Cherry Creek Drain, and Katzer Drain. Arnold Drain, which predominantly carries runoff and ground-water discharge derived from irrigation within the study area, is the only other perennial stream tributary to the North Platte River. Spring Creek parallels the North Platte River at the Wyoming-Nebraska State line and is the only stream other than the North Platte River that discharges from the study area (fig. 3). Data presented later in the report (table 10) shows that ground-water outflow was a substantial part of the North Platte River discharge from the study area from October 1970 through March 1971.

The U.S. Geological Survey has operated gaging stations (pl. 2) on the principal streams and drains in the area since the early 1900's. Discharge data for these stations during the period of this investigation are published by the U.S. Geological Survey (1970-71). Discharge data for the major canal diversions are maintained by the U.S. Bureau of Reclamation (U.S. Dept. of Interior, 1969-72). Gaging stations are operated on the Interstate Canal at Milepost 2.7, and on the Fort Laramie Canal at Milepost 0.8 near Whalen Dam, and at Milepost 85.3 at the Wyoming-Nebraska State line about 12 miles (19.3 km) south of the North Platte River (south of the report area). Milepost numbers indicate the number of canal miles from the diversion at Whalen Dam. The U.S. Geological Survey maintained a gaging station on the Interstate Canal at Milepost 50.8, about half a mile (0.8 km) from the State line in Nebraska, during the 1971 and 1972 irrigation seasons.

Quality of Water

The chemical analyses of water samples collected in 1970 and 1971 at the gaging stations on the Laramie River near Fort Laramie, the North Platte River near Lingle, Cherry Creek Drain near Torrington, and the North Platte River at Wyoming-Nebraska State line are published (U.S. Geological Survey, 1970-71, Pt. 2). An additional 30 samples of ground water and four samples of surface water were collected in 1971 and 1972 for chemical analysis (table 1).

No meaningful pattern of dissolved-solids concentration was ascertained from ground-water samples analyzed during this study. For the 30 ground-water samples, the mean dissolved-solids concentration was 615 mg/l and the standard deviation was 128 mg/l. Ground water that contains the lowest dissolved solids generally can be attributed to reecharge from a nearby stream or canal.

The major constituents in the ground water are calcium, sodium, bicarbonate, and sulfate. The predominant cation is calcium and the predominant anion is bicarbonate.

The major chemical constituents in the streams entering the area are calcium, sodium, bicarbonate, and sulfate, with calcium and bicarbonate the predominant cation and anion, respectively. Calcium is the predominant cation in the North Platte River at the Wyoming-Nebraska State line, although at that point sulfate is generally the predominant anion.

WATER BUDGET

Inflow

The term "inflow" is used in this report to include all water entering the study area from all sources. Sources of inflow to the hydrologic system of the valley fill are classified in four categories--streams, precipitation, imported surface water used for irrigation, and underflow. Inflow from precipitation and irrigation is subdivided into runoff and recharge. Runoff, as used in this report, is direct return flow to streams. Recharge is water that moves downward to the water table. Loss from the large canals is also divided into runoff and recharge. Part of the loss from the large canals moves directly to the streams and does not become ground-water recharge.

Table 1.--Chemical analyses of water

[Analytical results in milligrams per litre (mg/l) or micrograms per

Location	Well depth (ft)	Date of collection	Temperature (°C)	Silica (SiO_2) (mg/l)	Iron (Fe) (µg/l)	Calcium (Ca) (mg/l)	Magnesium (Mg) (mg/l)	Sodium (Na) (mg/l)	Potassium (K) (mg/l)
									Ground
									Lance
24-61-31bbb	160	5-25-72	15.0	11	50	4.3	1.4	250	5.1
25-61- 7dcd2	787	5-24-72	18.0	13	40	6.2	1.1	282	3.3
									Chadron
23-62- 5bbb	90	5-25-72	10.0	8.8	40	3.5	0.3	180	4.0
									Valley
23-60-10bdb	66	7- 2-71	10.5	22	30	49	13	140	4.7
15dab	80	7- 1-71	12.0	10	10	86	25	160	17
24-60- 3add2	110	5-24-72	16.0	45	30	110	7.7	50	.7
32bdc2	71	5-22-72	23.0	27	100	37	60	230	4.4
34cac	82	7- 1-71	19.0	47	10	96	21	94	11
24-61- 5cbb2	93	7- 1-71	14.5	52	10	93	17	63	15
6bca	54	5-24-72	9.0	39	50	100	20	72	12
10ccd2	40	7- 1-71	14.5	47	20	120	27	67	13
17abd2	30	5-24-72	13.0	28	50	98	24	70	7.0
21aab	62	8-17-71	13.0	27	10	110	29	99	8.9
24adb	36	8-17-71	13.5	50	10	110	20	70	10
24-62- 1bbb	60	7- 8-71	14.0	42	10	86	25	78	12
25-61-19baa	190	7- 7-71	14.0	58	10	45	10	82	9.9
28bcc	120	8-17-71	14.0	39	10	98	17	56	9.3
33dba	91	7-17-71	16.5	49	10	100	18	53	12
35dab	178	5-23-72	17.0	38	50	75	14	48	6.7
25-62- 3cba	90	7- 7-71	14.0	50	10	66	12	120	11
14bab	185	8-17-71	14.0	58	10	32	8.5	97	13
24bbb	165	7- 1-71	16.0	47	10	17	15	55	9.4
25-63- 3dcb	63	7- 7-71	15.0	52	10	89	15	56	13
12cbc	63	8-17-71	14.0	54	10	87	25	58	13
16bba	30	8-18-71	12.0	35	10	140	22	150	18
26-62-14baa	62	8-17-71	11.5	62	10	16	1.5	170	16

in the North Platte River valley
litre (µg/l) except as indicated. Analyses by U.S. Geological Survey.]

Bicarbonate (HCO_3) (mg/l)	Carbonate (CO_3) (mg/l)	Sulfate (SO_4) (mg/l)	Chloride (Cl) (mg/l)	Fluoride (F) (mg/l)	Nitrite (NO_2) + Nitrate (NO_3) (mg/l)	Boron (B) (µg/l)	Dis-solved solids Sum of con-stit-uents (mg/l)	Hardness as $CaCO_3$ (Ca, Mg) (mg/l)	Specific conduct-ance (micro-mhos at 25°C) 1/	pH (units) 1/
Water										
Formation										
427	0	160	23	0.6	0.2	140	665	17	1,080	8.3
727	0	4.9	8.3	3.4	4.2	440	684	20	1,160	9.8
Formation										
330	7	58	43	1.1	0.2	120	465	10	820	8.8
Fill										
309	0	220	19	1.0	0.29	220	622	180	990	7.6
454	0	250	28	.9	4.4	190	861	320	1,360	6.9
223	0	200	12	.5	21	50	549	300	885	7.8
446	0	180	29	1.6	.3	150	736	120	1,190	7.7
347	0	200	15	.7	4.2	160	674	330	1,000	6.8
272	0	180	15	.7	2.9	110	582	300	890	7.5
278	0	240	18	.6	13	70	651	340	940	6.9
347	0	220	20	.7	4.7	300	706	410	1,050	7.7
302	0	200	17	.6	21	100	610	340	915	8.0
390	0	270	22	.7	5.9	880	785	390	1,180	7.0
350	0	200	15	1.0	2.4	130	659	360	950	6.9
322	0	220	17	.7	2.6	100	651	320	980	7.2
196	0	160	17	.7	2.0	130	488	150	670	7.6
247	0	210	15	.8	3.1	370	581	310	840	7.3
260	0	200	16	.8	7.2	---	609	320	875	7.1
183	0	180	12	.4	4.8	60	471	240	690	7.2
300	0	220	19	.9	2.5	150	658	210	990	7.6
283	0	80	1.7	1.0	2.7	410	443	110	665	7.5
197	0	200	14	.5	.79	80	518	250	705	7.7
211	0	200	16	.5	3.6	110	561	280	690	7.4
270	0	210	16	1.0	2.6	380	609	320	865	7.0
385	0	430	21	.8	4.6	450	1,030	440	1,450	7.0
402	0	63	9.7	1.6	2.1	400	547	46	820	7.3

Table 1.--Chemical analyses of water

Location	Well depth (ft)	Date of collection	Temperature (°C)	Silica (SiO_2) (mg/l)	Iron (Fe) (µg/l)	Calcium (Ca) (mg/l)	Magnesium (Mg) (mg/l)	Sodium (Na) (mg/l)	Potassium (K) (mg/l)
									Ground
									Valley
26-63-32cba	63	7- 8-71	14.0	32	10	78	20	59	4.9
32dac	80	8-17-71	16.5	29	10	77	19	53	6.5
26-64-15cdb	52	7- 8-71	15.5	30	10	58	16	48	6.2
29bba	83	7- 8-71	14.0	25	10	100	19	75	4.3
									Surface
	Discharge (ft^3/s)								
Station 06671000 Rawhide Creek	22.1	7- 8-71	17.0	38	20	56	15	91	10
Station 06673000 Arnold Drain	----	5-23-72	27.0	31	70	65	11	91	7.7
Station 06673005 North Platte Ditch Waste	4.0	7- 7-71	20.0	30	30	54	18	40	18
Station 0667350 Katzer Drain	70.0	6-30-71	24.0	30	30	42	17	110	8.9

in the North Platte River valley--continued

Bicarbonate (HCO_3) (mg/l)	Carbonate (CO_3) (mg/l)	Sulfate (SO_4) (mg/l)	Chloride (Cl) (mg/l)	Fluoride (F) (mg/l)	Nitrite (NO_2) + Nitrate (NO_3) (mg/l)	Boron (B) (μg/l)	Dissolved solids Sum of constituents (mg/l)	Hardness as $CaCO_3$ (Ca, Mg) (mg/l)	Specific conductance (micromhos at 25°C) 1/	pH (units) 1/
Water										
Formation										
257	0	180	14	0.6	0.81	90	518	280	800	7.5
227	0	190	14	.7	1.2	90	506	270	770	7.2
222	0	130	11	.8	2.9	140	422	210	590	7.2
275	0	220	15	.5	1.2	120	599	330	880	7.5
Water										
251	0	170	14	0.7	1.2	130	524	206	780	8.2
164	0	165	12	.5	.7	80	417	209	610	8.2
165	0	130	9.1	.5	.34	100	350	210	590	8.3
237	0	210	18	.6	1.4	160	545	170	880	---

1/ Measured in the field.

Streams

Stream discharges are measured at U.S. Geological Survey gaging stations on all the streams (U.S. Geological Survey, 1970-71) except Sand Draw near Barnes, Sand Draw near Lingle, Arnold Drain, and Spring Creek. The discharges of these streams during the irrigation season are determined on the basis of periodic measurements and daily staff gage readings by the Assistant Hydrographer--Commissioner, Water Division 1, Torrington, Wyo. (written commun., 1970). Discharges of these streams during the nonirrigation season were estimated. Inflow to the system from Rawhide Creek during the irrigation season was estimated because the discharges measured at the gaging station reflect pickup from irrigation within the system.

Precipitation

Runoff from precipitation in the modeled area (table 2) was estimated from the mean of precipitation measured at three gages in the area (U.S. Department of Commerice, 1970), effective precipitation, and mean consumptive use of crops. Part of the precipitation is intercepted by vegetation and evaporated. Effective precipitation is defined in this report as that part of precipitation falling on an area that is effective in meeting the consumptive use requirement. The effective precipitation and consumptive use were estimated from data given by Trelease and others (1970). The effective precipitation was estimated by multiplying the monthly mean precipitation at the three gages by the appropriate percent as given by Trelease and others (1970, p. 11). Their table is reproduced in part.

Amount of precipitation in any month (in inches)	Percent considered effective
1	95
2	90
3	82
4	65
5	45
6	25
over 6	5

Table 2.--Estimated runoff and recharge in the modeled area

	1970			
	Apr.	May	June	July
	Total monthly precipitation (in inches)			
Precipitation station 1/				
Lingle 3 S	1.18	1.34	4.77	2.21
Torrington Exp. Farm	1.55	1.12	4.02	2.01
Whalen Dam	1.70	1.05	4.66	1.96
Total	4.43	3.51	13.45	6.18
	Monthly mean			
	1.48	1.17	4.48	2.06
	Monthly effective			
	1.41	1.11	2.91	1.85
	Monthly mean			
Irrigated lands 3/	1.22	3.42	5.43	6.76
Nonirrigated lands 4/	2.28	4.43	6.22	7.18
	Monthly runoff from			
Irrigated lands	160			
Nonirrigated lands	---			
Total	160			
	Monthly recharge from			
Irrigated lands	640			
Nonirrigated lands	---			
Total	640			

1/ U.S. Department of Commerce, 1970.
2/ It was assumed a negligible amount of runoff or recharge occurred during January, February, November, and December.
3/ Total acreage in modeled area is about 89,000 acres, of which about 50,750 acres are irrigated.
4/ Assumed all grass, hay, or pasture lands.
5/ Total water available = [(effective precipitation) - (mean consumptive use)] x acres. Runoff = (Total water available) x 0.20.
6/ Recharge = (Total water available) - (Runoff).

from precipitation in the North Platte River valley

1970					1971		
Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
recorded at precipitation stations							
0.32	0.51	1.27	0.03	0.16	0.24	0.38	0.61
.05	.47	1.90	.03	.11	.22	.46	.45
.39	.79	1.50	.05	.22	.23	.56	.87
.76	1.77	4.67	.11	.49	.69	1.40	1.93
precipitation (in inches)							
0.25	0.59	1.56	0.04	0.16	0.23	0.47	0.64
precipitation (in inches)							
0.24	0.56	1.40	0.04	0.15	0.22	0.45	0.61
consumptive use (in inches) 2/							
4.81	2.57	0.39	----	----	----	----	0.27
5.86	3.53	1.85	----	----	----	----	.12
precipitation (in acre-feet) 5/							
		850					290
		---					310
		850					600
precipitation (in acre-feet) 6/							
		3,420					1,150
		-----					1,240
		3,420					2,390

Calculations have been made for the monthly consumptive use for seven crops (alfalfa, beans, corn, grass or hay, potatoes, small grain, and sugar beets) at the University of Wyoming Experiment Farm, Torrington, Wyo. (Trelease and others, 1970). It was assumed that the mean of the consumptive use of the seven crops in each month would equal the consumptive use for that month (table 3), and that effective precipitation in excess of the consumptive use becomes either runoff or recharge. Many parameters determine the amount of runoff and recharge from each storm. Because data for these parameters are not available for the period of this investigation, it is impossible to determine a monthly average value for percent of runoff and recharge. For lack of better data, it was assumed that any effective precipitation in excess of consumptive use during a month was divided into 20 percent runoff and 80 percent recharge.

Table 3.--Estimated consumptive irrigation requirement for 1970 in the North Platte River valley.

	Mean consumptive use (in)	Effective precipitation (in)	Consumptive irrigation requirement (in)
May	3.42	1.11	2.31
June	5.43	2.91	2.52
July	6.76	1.85	4.91
August	4.81	.24	4.57
September	2.57	.56	2.01

In the North Platte valley most of the precipitation occurs during the growing season (May through Sept.). Effective precipitation for the irrigation season (May through Sept.) was deducted from the mean monthly consumptive use (table 3). The remainder is the monthly consumptive irrigation requirement (tables 3 and 4). Any runoff or recharge that may have occurred from precipitation during the irrigation season is included in the values of runoff and recharge listed for the canal diversions (table 4).

The amount of precipitation that occurred in the period November 1970 through February 1971 was small. The largest amount of precipitation from a single storm was about 0.2 inch (5.08 mm) (assumed to be snow) that occurred in February. Runoff and (or) recharge probably did not occur until March; therefore, it was assumed that a negligible amount of precipitation actually became runoff or recharge during these 4 months.

Irrigation

Seepage from surface-water irrigation contributes much of the recharge to the ground-water reservoir (table 4); however, only the diversions from the Interstate and the Fort Laramie Canals contribute water to the system. These two canals carry surface water that is imported for irrigation. The water is considered to have entered the system after entering the canals at Whalen Dam (fig. 3). Other canals that divert water from the North Platte River (under "North Platte River diversions," table 4) are totally within the system and therefore do not contribute water.

Both the Interstate Canal and the Fort Laramie Canal carry water into Nebraska. Canal loss in Wyoming from these canals was determined as the difference between the amount diverted at Whalen Dam, less diversion for irrigation in Wyoming, and the total discharge at gaging stations at the Wyoming-Nebraska State line.

Most of the loss from the large canals is recharge to ground water. Loss from the Interstate Canal was estimated from discharge measurements at Milepost 50.8 where a gaging station was operated during canal operation in 1971 and 1972. Canal loss for 1970 (table 5) was estimated as the mean of the canal losses that were measured in 1971 and 1972.

It was estimated that the Fort Laramie Canal contributes water to the modeled area in a 58.7-mile (94.4-km) reach extending from Whalen Dam to Cherry Creek lateral. This reach is about 70 percent of the 85.3 miles (137.3 km) of the Fort Laramie Canal in Wyoming. Assuming uniform distribution of losses, about 70 percent of the total losses to Milepost 85.3 occur within the modeled area (table 6).

Part of the water loss from the Interstate Canal and the Fort Laramie Canal moves directly to the streams as runoff. After deduction of evaporation, runoff was estimated to be 20 percent of the loss from the Interstate Canal and 30 percent of the loss from the Fort Laramie Canal (tables 5 and 6).

Runoff from surface-water irrigation (table 4) was estimated to be 15 percent of the canal diversion for lands irrigated from all canals, except the Fort Laramie Canal. Runoff from lands irrigated from the Fort Laramie Canal was estimated to be 30 percent of the diversions. These assumptions are based on estimates made by local water managers.

Underflow

Underflow is subsurface movement of ground water. The largest amount of underflow into the system occurs through the sand and gravel deposits in the valleys of the North Platte River, the Laramie River, and Rawhide Creek. Underflow was assumed to remain constant over time and was calculated in the stream valleys (table 7) by using the saturated thickness map and water-table map and applying Darcy's flow equation (Darcy, 1856).

Leakage between the valley fill and the underlying bedrock formations was not determined. Because of the low permeabilities in the bedrock formations, the amount of leakage was considered to be within the error of estimates used in the water budget for the modeled area [table 11]. Leakage across the valley-fill-bedrock boundary was neglected in most areas. But, in the area extending about 5 miles (8.0 km) east from Rawhide Creek and north of the Interstate Canal, underflow is estimated to be 280 acre-feet ($1.05 \times 10^5 m^3$) per month.

Outflow

Outflow from the system is by surface flow (streams and the Gering-Mitchell Canal), underflow, and evapotranspiration. Only that part of pumpage that is lost to consumptive use is included as part of the outflow.

Surface Flow

Most of the water leaving the system by surface flow is measured. Discharge of the North Platte River is measured at a gaging station at the Wyoming-Nebraska State line. Diversion from the North Platte River into the Gering-Mitchell Canal is also measured near the State line. Discharge of Spring Creek is estimated.

Underflow

Underflow out of the system occurs in the sand and gravel deposits in the North Platte valley and in the terrace deposits along the State line. The underflow (table 8) was calculated using Darcy's flow equation (Darcy, 1856) and was assumed to remain constant over time.

Table 5.--Estimated distribution of losses from the Interstate Canal in 1970

[Amounts in acre-feet]

Month	Discharge at Milepost 2.7	Canal loss in Wyoming 1/	Evaporation loss 2/	Canal loss less evaporation loss	Distribution of canal loss: Runoff 3/	Distribution of canal loss: Recharge
April	28,600	4,950	120	4,830	970	3,860
May	76,410	8,860	240	8,620	1,720	6,900
June	40,860	5,390	270	5,120	1,020	4,100
July	121,180	7,270	280	6,990	1,400	5,590
August	121,940	6,340	270	6,070	1,210	4,860
September	96,070	4,130	180	3,950	790	3,160
October	17,840	540				
Total	502,900	37,480	1,360	35,580	7,110	28,470

1/ Canal loss estimated from discharge measurements at milepost 50.8 where a gaging station was operated during canal operation in 1971 and 1972.

2/ Evaporation was estimated by using the following method:
Area of open water = 370 acres (50.8 miles long and 60 feet wide).
Annual evaporation rate from open water estimated to be 44 inches (Meyers, 1962, pl. 3).
Total evaporation = 1,360 acre-feet per year.
Evaporation prorated on the losses of percent pan evaporation (at Whalen Dam in 1970) occurring each month, April through September.

Month	Percent of total evaporation
April	8.8
May	17.7
June	19.5
July	20.5
August	20.2
September	13.3

3/ Runoff estimated to be 20 percent of canal loss after reduction of evaporation. This part of the canal loss moves directly to streams.

Table 6.--Estimated diversions and distribution of losses

[Amounts in

Month	Diversion to Goshen Irrig. District	Fort Laramie Canal loss in Wyoming	Distribution of Fort Laramie	
			Loss to modeled area 1/	Evaporation 2/
May	12,560	3,730	2,610	310
June	17,370	3,130	2,190	340
July	42,400	3,660	2,560	350
August	44,670	2,710	1,900	350
September	29,460	1,430	1,000	230
Total	146,460	14,660	10,260	1,580

1/ It is estimated that about 70 percent of total canal losses are contributed to the modeled area. This is based on 58.7 miles, out of the 85.3 miles of the Fort Laramie Canal in Wyoming, contributing to the modeled area and assuming even distribution of the loss.

2/ Evaporation was estimated using the following method:
Area of open water = 430 acres (58.7 miles long and 60 feet wide).
Annual evaporation rate from open water estimated to be 44 inches (Meyers, 1962, pl. 3).
Total evaporation = 1,580 acre-feet per year.
Evaporation prorated on the basis of pan evaporation (at Whalen Dam, 1970) occurring each month, May through September.

Month	Percent of total evaporation	Evaporation in acre-feet
May	19.4	310
June	21.4	340
July	22.5	350
August	22.1	350
September	14.6	230
Total	100.0	1,580

from the Fort Laramie Canal in 1970

acre-feet]

losses from Canal			Delivered to laterals in Wyoming	Diversions to irrigate modeled area 4/
Canal loss	Runoff 3/	Recharge		
2,300	690	1,610	6,890	2,200
1,850	560	1,290	12,710	4,070
2,210	660	1,550	37,510	12,000
1,550	460	1,090	41,850	13,400
770	230	540	26,120	8,360
8,680	2,600	6,080	125,080	40,030

3/ Runoff estimated to be 30 percent of canal loss after deduction of evaporation. This part of the canal loss moves directly to streams.

4/ It is estimated that 32 percent of water delivered to laterals in Wyoming is delivered to the modeled area on the basis that 16,400 acres are irrigated in the modeled area and a total of 51,700 acres are irrigated by water delivered to laterals in Wyoming.

Table 7.--Underflow into the system through sand and gravel deposits along the North Platte River, Laramie River, and Rawhide Creek.

Location	Weighted average depth of saturation (ft)	Width of saturation (ft)	Average gradient (ft/mi)	Hydraulic conductivity (ft/d)	Underflow (ac-ft/mo)
North Platte River - at sec. line between Rs. 64 and 65 W.	109	3,600	10	600	310
Laramie River - at sec. line between Rs. 64 and 65 W.	109	3,600	6	600	190
Rawhide Creek - at sec. line north of Interstate Canal	72	9,500	15	90	120

Table 8.--Underflow out of the system at the Wyoming-Nebraska State line.

Aquifer material	Weighted average depth of saturation (ft)	Width of saturation (ft)	Average gradient (ft/mi)	Hydraulic conductivity (ft/d)	Underflow (ac-ft/mo)
Sand and gravel deposits along the North Platte River-------------	70	17,000	6	600	570
Terrace deposits----	75	23,300	13	285	860

Evapotranspiration

Evapotranspiration includes water lost to consumptive use by irrigated crops and water lost from areas of shallow water table. Consumptive use from only those lands irrigated by surface water diverted from the North Platte River below Whalen Dam and lands irrigated by ground water is lost from the system. Consumptive use from other irrigated lands is not considered as a loss from the system because that water is not considered to have ever been added to the system.

Lands irrigated by diversions from the North Platte River below Whalen Dam are listed under "North Platte River Diversions" (table 4). After subtracting consumptive use, the remaining water from these diversions is being circulated within the system and is neither inflow to nor outflow from the system.

Evapotranspiration from the water table occurs in areas where the water table is close to the land surface. It has been estimated (Rapp and others, 1957, p. 64) that evapotranspiration would be about 1.5 feet (0.46 m) annually where the water table is less than 10 feet (3.05 m) deep. Within the modeled area, depth to water is 10 feet (3.05 m) or less under about 15,800 acres ($6.4 \times 10^7 m^2$). The amount of evapotranspiration for each month was prorated on the basis of the percent of total monthly pan evaporation at Whalen Dam in 1970 from April through September. (See table 5, footnote 2.) Losses to phreatophytes are assumed to be included in the losses attributed to evapotranspiration from the shallow water table.

Pumpage

Annual pumpage from wells used for irrigation, industry, and municipal supplies was estimated (table 9) by using records of electric-power and natural-gas consumption and data from power-consumption tests. Electric-power records were obtained from Wyrulec Company and the city of Torrington. Kansas-Nebraska Natural Gas Company, Inc., supplied records of natural gas used for pumping irrigation wells. Power use tests were run on 31 irrigation wells in the study area during the 1970 irrigation season. Pumpage at the 31 wells was estimated by dividing the power consumption (in terms of kilowatt hours per acre-foot of water or cubic feet of natural gas per acre-foot of water) into the total kilowatt hours or cubic feet of natural gas used, respectively. The mean power consumption (in terms of amount of power or fuel used per acre-foot of water per foot of lift) was used to estimate pumpage from wells where power or fuel records were available but efficiency tests were not made. About 30 percent of the 220 wells pumped in 1970 were not powered by either electricity or natural gas. Pumpage from these wells was assumed to equal the average pumpage of the wells where power consumption was measured. In 1970 the power consumption was measured for about 70 percent of the wells.

Table 9.--Estimated pumpage from irrigation and

[in acre-feet]

Estimated number of wells pumped	Year	Power	January	February	March	April	May
	1969						
112		electric	400	300	400	1,490	2,860
37		natural gas	---	---	---	300	1,380
61		other	---	---	---	730	1,740
Totals 210			400	300	400	2,520	5,980
	1970						
116		electric	390	390	340	540	2,660
38		natural gas	---	10	---	-----	260
66		other	---	---	---	-----	1,250
Totals 220			390	400	340	540	4,170
	1971						
128		electric	380	380	290	720	990
38		natural gas	10	---	---	60	190
60		other	---	---	---	280	430
Totals 226			390	380	290	1,060	1,610
	1972						
133		electric	510	780	730	590	5,370
38		natural gas	---	---	10	30	150
60		other	---	---	---	220	1,940
Totals 231			510	780	740	840	7,460

municipal wells in the North Platte River valley

June	July	August	September	October	November	December	Total
4,500	7,820	4,650	2,040	920	420	450	26,250
1,920	2,690	4,500	4,360	1,220	110	---	16,480
2,630	4,300	3,750	2,620	880	---	---	16,650
9,050	14,810	12,900	9,020	3,020	530	450	59,380
5,110	5,540	3,250	2,570	480	460	450	22,180
1,680	2,730	3,290	1,720	480	70	---	10,240
2,910	3,540	2,800	1,840	---	---	---	12,340
9,700	11,810	9,340	6,130	960	530	450	44,760
5,180	7,160	4,730	970	380	210	240	21,630
150	2,380	5,080	1,480	120	140	---	9,610
1,930	3,450	3,550	890	220	---	---	10,470
7,260	12,990	13,360	3,340	720	350	240	41,710
7,870	7,750	4,080	1,420	980	590	530	31,200
1,160	2,390	1,980	1,190	520	60	---	7,490
3,170	3,560	2,130	880	530	---	---	12,430
12,200	13,700	8,190	3,490	2,030	650	530	51,120

Because about 45 percent of the surface-water diversions are lost by consumptive use, it was assumed that 45 percent of the gross pumpage from April through September would be similarly lost by consumptive use. (During other months of the year, consumptive use is assumed to be 10 percent of the pumpage.) The remaining water is assumed to be recharge and therefore stays in the system. In the water budget for the system, only that part of pumpage that is consumed is considered as outflow. Recharge from ground-water pumpage is not listed because that water was initially in the system and is neither inflow nor outflow from the hydrologic system of the valley fill.

Summary of Water Budget

Two water budgets are given from April 1970 through March 1971. One budget of the surface water alone is used to estimate the net gain or net loss in the North Platte River in the study area. A second budget for the entire hydrologic system includes all water entering and leaving the valley fill.

The budget for the North Platte River (table 10) lists the surface-water inflow and outflow and the amount of ground water discharged to the river. A negative ground-water discharge indicates a net loss of river water; that is, more water is being diverted from the river than is being contributed to the river by ground-water discharge. This occurs during May and June when water is first diverted from the North Platte River for irrigation and ground-water recharge from these diversions has not yet affected the river.

The accuracy of the estimate of ground-water discharge to the river is primarily dependent on the accuracy of the estimates for runoff and evaporation from the North Platte River. The effect of large changes in the values estimated for runoff and evaporation can be illustrated. Minimum runoff (zero) would reduce the amount of inflow (table 10) by about 7 percent. The maximum amount of runoff that could be expected would increase the amount of runoff by about 14 percent. Changing the estimated value of evaporation from the North Platte River by an order of magnitude would affect the amount of outflow by less than 10 percent.

The budget for the entire hydrologic system (table 11) lists the total inflow and outflow from all sources. The amount of water moving into the area equals the amount of water moving out, plus or minus the amount of change in storage within the area. Data tabulated in table 11 shows that outflow exceeded the inflow by 36,280 acre-feet ($44.7 \times 10^6 m^3$), indicating a depletion of storage during the period April 1970 through March 1971. The difference amounts to about 6 percent of the total water involved.

The most accurate data in tables 10 and 11 are the stream discharges and canal diversions, which may be accurate to within 5 percent. Therefore, the 6 percent difference between inflow and outflow is not considered to be significant, and it can be assumed that no net change in storage occurred between April 1970 and March 1971. Between April 1970 and March 1971, there was less than 1 foot (0.3 m) of change in the water level in 27 of the 38 observation wells. Water levels in most of the other 11 observation wells were influenced by nearby pumping early in the spring each year; however, the small quantity of early pumpage probably would not affect the total net storage by a measurable amount. As added information, water-level measurements during the last 20 years (1952-72) in seven observation wells and during the last 10 years (1962-72) in eight observation wells showed that there was little or no change in the long-term water levels.

Table 10.--Water budget for the

[Amounts in

	1970			
	April	May	June	July
Inflow				
A. Streams				
North Platte River	5,300	39,520	85,140	84,300
Laramie River	11,550	26,370	50,450	15,350
Sand Draw near Barnes			50	
Sand Draw near Lingle		90	140	140
Rawhide Creek	770	1,320	1,500	540
Cherry Creek Drain	660	1,060	4,480	2,870
Arnold Drain	50	130	190	280
Katzer Drain	620	1,110	6,370	3,660
Subtotal (streams)	18,950	69,600	148,320	107,140
B. Runoff				
Precipitation	160			
Irrigation (surface water)		2,500	3,080	8,030
Loss from large canals 1/	970	2,410	1,580	1,860
Subtotal (runoff)	1,130	4,910	4,660	9,890
Total Inflow, less ground-water pickup	20,080	74,510	152,980	117,030
Outflow				
A. Streams				
North Platte River	22,620	55,020	129,100	85,250
B. Canal diversions 2/				
Burbank Ditch		20	10	220
Lucerne Canal and Power Co.		1,910	3,010	3,750
New Grattan Ditch Co.		60	240	800
Torrington Irrigation Dist.		1,360	1,400	2,160
Rock Ranch Ditch		980	2,570	2,950
North Platte Irrig. Ditch Co.		1,080	800	2,480
Pratte-Ferris			550	450
Gering-Mitchell Canal		5,480	9,940	20,630
Subtotal (diversions)		10,890	18,520	33,440
C. Evaporation from North Platte R.	490	980	1,080	1,140
Total Outflow	23,110	66,890	148,700	119,830
Ground-water discharge to the river 3/	3,030	-7,620	-4,280	2,800

1/ See tables 5 and 6.
2/ See table 4.
3/ (-) Indicates more water is being diverted from the river than is being contributed to the river by ground-water discharge.

North Platte River in the modeled area

acre-feet]

1970					1971			
Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Totals
73,370	21,890	6,360	1,510	170	40	20	190	317,810
4,180	2,730	7,600	8,550	7,620	8,160	8,280	14,170	165,010
								50
190	180							740
770	1,200	1,460	1,090	910	700	600	710	11,570
3,300	3,880	1,130	760	580	560	600	600	20,480
340	310	150	100	50	50	50	50	1,750
3,600	3,800	770	700	1,150	580	450	520	23,330
85,750	33,990	17,470	12,710	10,480	10,090	10,000	16,240	540,740
		850					600	1,610
8,630	5,370							27,610
1,670	1,020							9,510
10,300	6,390	850					600	38,730
96,050	40,380	18,320	12,710	10,480	10,090	10,000	16,840	579,470
67,380	37,730	34,740	25,750	21,200	19,780	16,730	19,750	535,050
300	150							700
3,640	2,590							14,900
440	350							1,890
2,160	1,870							8,950
2,690	1,910							11,100
2,810	1,340							8,510
720	450							2,170
19,670	11,250							66,970
32,430	19,910							115,190
1,120	740							5,550
100,930	58,380	34,740	25,750	21,200	19,780	16,730	19,750	655,790
4,880	18,000	16,420	13,040	10,720	9,690	6,730	2,910	76,320

Table 11.--Water budget

[Amounts in

	1970			
	April	May	June	July
Inflow				
A. Streams				
North Platte River-----------	5,300	39,520	85,140	84,300
Laramie River----------------	11,550	26,370	50,450	15,350
Sand Draw near Barnes--------			50	
Sand Draw near Lingle--------		90	140	140
Rawhide Creek----------------	770	700	700	700
Cherry Creek Drain-----------	660	1,060	4,480	2,870
Katzer Drain-----------------	620	1,110	6,370	3,660
Subtotal (streams)------	18,900	68,850	147,330	107,020
B. Runoff				
Precipitation----------------	160			
Interstate Canal, Fort Laramie Canal, and Wright and Murphy Ditch diversions------------		1,690	1,790	6,120
Loss from large canals-------	970	2,410	1,580	1,860
Subtotal (runoff)-------	1,130	4,100	3,370	7,980
C. Underflow				
Terrace deposits-------------	280	280	280	280
North Platte River valley----	310	310	310	310
Laramie River valley---------	190	190	190	190
Rawhide Creek valley---------	120	120	120	120
Subtotal (underflow)----	900	900	900	900
D. Recharge				
Precipitation----------------	640			
Interstate Canal-------------	3,860	6,900	4,100	5,590
Fort Laramie Canal-----------		1,610	1,290	1,550
Interstate Canal diversions--		2,290	220	6,540
Fort Laramie Canal diversions			640	1,790
Subtotal (recharge)-----	4,500	10,800	6,250	15,470
Total Inflow----------------------	25,430	84,650	157,850	131,370

for the system

acre-feet]

1970					1971			
Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Totals
73,370	21,890	6,360	1,510	170	40	20	190	317,810
4,180	2,730	7,600	8,550	7,620	8,160	8,280	14,170	165,010
								50
190	180							740
700	700	700	700	700	700	600	710	8,380
3,300	3,880	1,130	760	580	560	600	600	20,480
3,600	3,800	770	700	1,150	580	450	520	23,330
85,340	33,180	16,560	12,220	10,220	10,040	9,950	16,190	535,800
		850					600	1,610
6,710	4,070							20,380
1,670	1,020							9,510
8,380	5,090	850					600	31,500
280	280	280	280	280	280	280	280	3,360
310	310	310	310	310	310	310	310	3,720
190	190	190	190	190	190	190	190	2,280
120	120	120	120	120	120	120	120	1,440
900	900	900	900	900	900	900	900	10,800
		3,420					2,390	6,450
4,860	3,160							28,470
1,090	540							6,080
8,080	5,590							22,720
3,220	3,170							8,820
17,250	12,460	3,420					2,390	72,540
111,870	51,630	21,730	13,120	11,120	10,940	10,850	20,080	650,640

Table 11.--Water budget

[Amounts in

	1970			
	April	May	June	July
Outflow				
A. Streams				
North Platte River----------	22,620	55,020	129,100	85,250
Spring Creek----------------	430	430	430	430
Subtotal (streams)------	23,050	55,450	129,530	85,680
B. Gering-Mitchell Canal----------		5,480	9,940	20,630
C. Underflow				
North Platte River valley----	570	570	570	570
Terrace deposits------------	860	860	860	860
Subtotal (underflow)----	1,430	1,430	1,430	1,430
D. Evapotranspiration				
From North Platte River diversions----------------		2,470	3,060	6,130
From pumpage----------------	240	1,880	4,370	5,310
From shallow water table-----	2,050	4,270	4,580	4,900
Subtotal (evapotranspiration)----	2,290	8,620	12,010	16,340
Total Outflow--------------------	26,770	70,980	152,910	124,080
Net change [Increase (+), decrease (-)]-----------	-1,340	13,670	4,940	7,290

for the system--continued

acre-feet]

1970					1971			
Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Totals
67,380	37,730	34,740	25,750	21,200	19,780	16,730	19,750	535,050
430	430	430	430	430	430	430	430	5,160
67,810	38,160	35,170	26,180	21,630	20,210	17,160	20,180	540,210
19,670	11,250							66,970
570	570	570	570	570	570	570	570	6,840
860	860	860	860	860	860	860	860	10,320
1,430	1,430	1,430	1,430	1,430	1,430	1,430	1,430	17,160
5,840	2,620							20,120
4,200	2,760							18,760
4,740	3,160							23,700
14,780	8,540							62,580
103,690	59,380	36,600	27,610	23,060	21,640	18,590	21,610	686,920
8,180	-7,750	-14,870	-14,490	-11,940	-10,700	-7,740	-1,530	-36,280

DIGITAL MODEL

The theory of the aquifer model used in this study is explained by Pinder and Bredehoeft (1968). The general computer program for the digital model was written by G. F. Pinder (1970) of the U.S. Geological Survey. Leonard F. Konikow of the U.S. Geological Survey modified the general program for application to the North Platte River valley.

The model was constructed to simulate hydrologic conditions in the valley fill using inflow-outflow data and water-level changes measured in the aquifer from April 1970 through March 1971. Stress on the hydrologic system is caused by application of surface water for irrigation, seepage from canals, pumpage, evapotranspiration, and precipitation. These stresses are treated as monthly variables of recharge or discharge in the aquifer, starting from initial conditions on April 1, 1970.

Effects of these stresses on ground water and surface water are measured as head changes in the aquifer and as ground-water discharge to the North Platte River. Ground-water pickup in the North Platte River is simulated in the model but total stream discharge is not. The model can be used, after calibration, to predict the general effects of simulated stresses on the water table and on the ground-water discharge to the North Platte River.

Method.--A rectangular grid (fig. 4) was superimposed on maps of the area. The center of each rectangle in the grid is a node. Parameter cards were prepared, listing input data at each node.

The saturated part of the valley fill is modeled. (See pl. 3.) Where there is saturation in the valley fill at the edge of the model, underflow is simulated by either recharge or discharge. Elsewhere, the lateral boundary of the model is the line of zero saturated thickness. Those cells (rectangles) that are located outside the modeled area are assigned zero hydraulic conductivity.

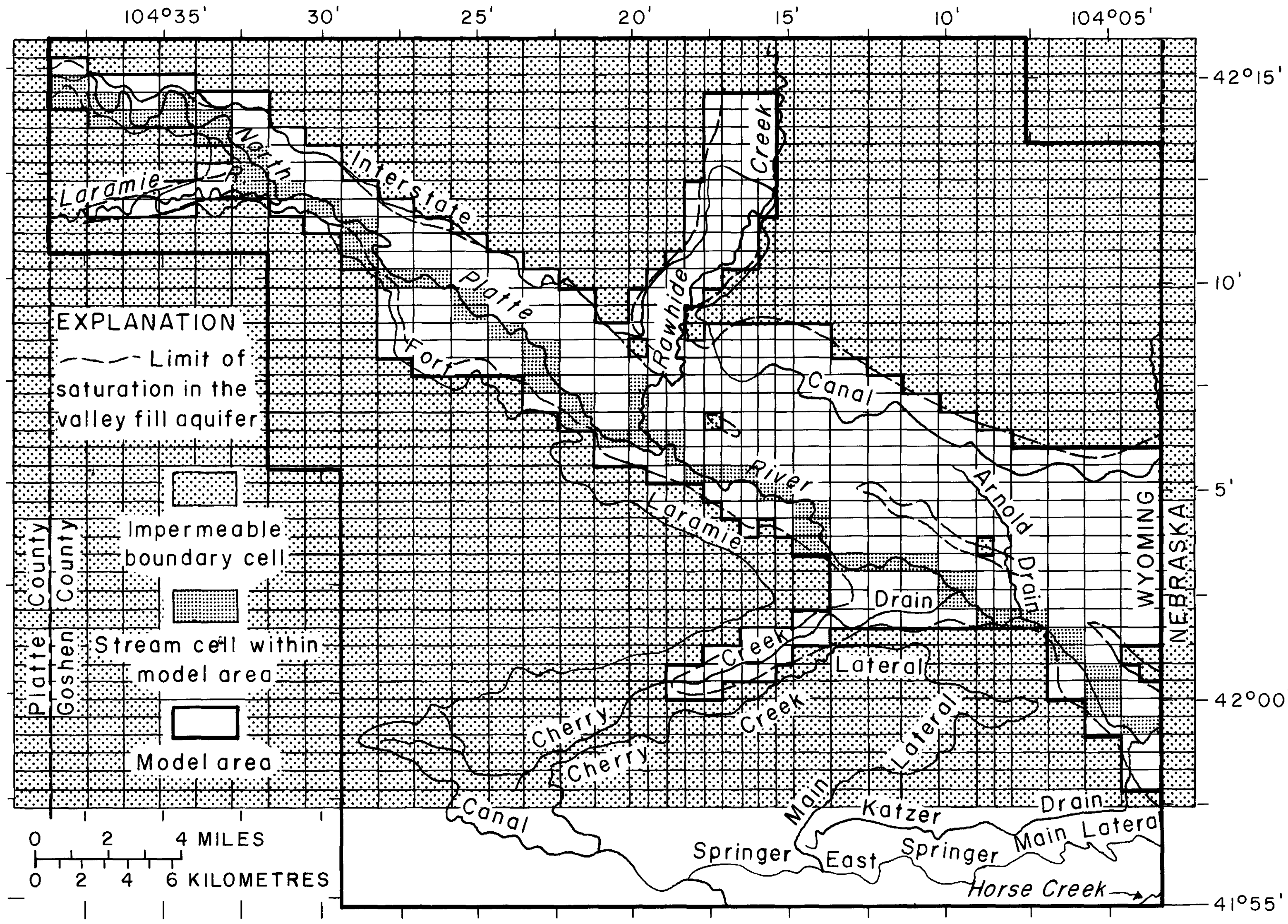

Figure 4.-Rectangular grid used to model the valley fill.

Listed below are assumptions made to simplify the actual field conditions in the hydrologic system in a form more suitable for modeling.

1. Pumpage was assumed to be evenly distributed to 220 wells during May through September. During other months of the year, pumpage was assumed to occur only at those wells where power consumption was measured. Each well is represented in the model at the closest node of the finite-difference grid.

2. Surface-water irrigation occurred only during the months of May through September.

3. Surface-water irrigation was applied each month at the rate of total monthly diversion divided by total irrigated acres.

4. All perennial streams are line sources or sinks (recharge or discharge, respectively).

5. Recharge to ground water from the Interstate Canal and the Fort Laramie Canal can be simulated by recharging wells during operation of the canals.

6. The water levels measured in April 1971 are equal to the water levels in April 1970.

7. The mean monthly stage measured at three gaging stations on the North Platte River is representative of the stage throughout the stream.

8. Aquifer parameters are average for the node area.

9. Soil-moisture storage could be neglected.

Data input.--The following data are provided for each node:

1. Area of cell in the grid--arbitrarily chosen so that sufficient detail is provided to simulate conditions in the aquifer. The number of nodes is limited by the amount of storage in the computer.

2. Altitude of initial hydraulic head in the aquifer--obtained from the water-table map.

3. Ratio of vertical hydraulic conductivity to thickness of streambed at stream cells. No field values were measured; therefore, a large value was assigned to assure that a constant head was maintained in the aquifer at the stream cells during the month.

4. Average hydraulic conductivity for each cell--estimated from aquifer tests or assumed where no data are available.

5. Altitude of the base of the aquifer measured from the same datum as hydraulic head--obtained from contour map showing configuration of the bedrock surface.

6. Storage coefficient--an average value assigned throughout the model and assumed equal to a specific yield of 0.23.

7. Number of wells--number of wells pumping during the season.

8. Node identification--node identification was assigned in the model to show the location of streams and location of land irrigated by surface water from canals. Land not irrigated, or irrigated wholly by ground water, is not identified. The acreage irrigated by each canal is considered to be constant for the season.

Nodes identified as "stream cell" are along the North Platte River and extend upstream of tributaries to the gaging stations. Ground water contributed to the "stream cells" is dependent upon the altitude of the water level in those cells.

The initial altitude (April 1970) of the water level in the "stream cells" was assumed to be the same altitude as the potentiometric surface (pl. 2). Each month thereafter the altitude in the "stream cells" changed because of change in stage of the river. The monthly mean gage height of three gaging stations on the North Platte River (below Whalen Dam, near Lingle, and at the Wyoming-Nebraska State line) was calculated. After April, the net change in monthly mean gage height between the current month and the previous month was used as the estimate of the net change of altitude of the water level in the "stream cells" caused by changing stream stage (fig. 5).

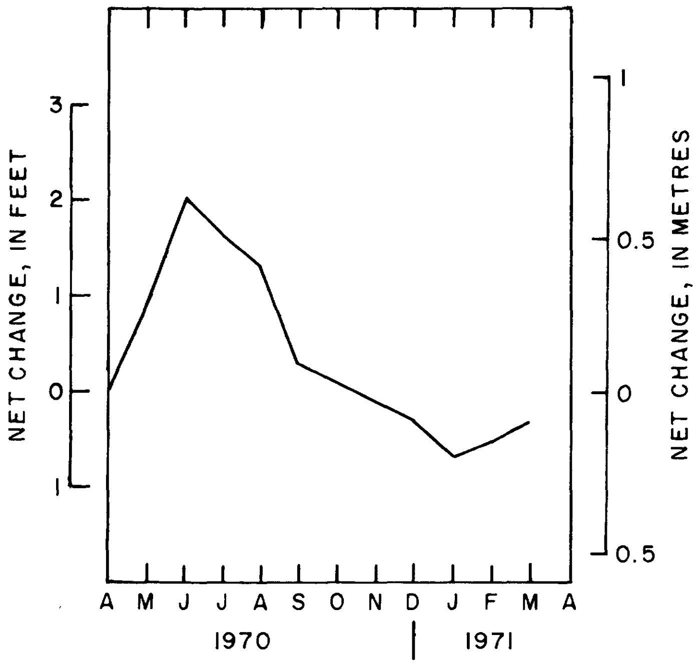

Figure 5.-- Estimated monthly net change in altitude of the water level in "stream cells" caused by changing stream stage.

Some data vary during the season and are given new values for each month. These include:

1. Rate of consumptive use.

2. Consumptive use of ground water. Estimated to be 45 and 10 percent of pumpage during the irrigation and nonirrigation seasons, respectively.

3. Rate of evapotranspiration.

4. Diversions to each canal.

5. Recharge from precipitation (except for months May through September).

6. Runoff from precipitation (except for months May through September).

7. Estimated average change of stage in the cells identified as "stream cells."

Data output.--Printouts from the digital model give the monthly net water-level change in the aquifer at each node and the monthly net discharge of ground water to the North Platte River between Whalen Dam and the State line for the one-year study period.

Calibration.--The model was calibrated by comparing data generated in the model with (1) the monthly net discharge of ground water to the North Platte River (table 10), and (2) the monthly net water-level changes measured in observation wells. Adjustments were made in the hydrologic parameters that were used to construct the model to achieve agreement between data in the tables and data generated in the model. Principal hydrologic parameters adjusted were the altitude of initial hydraulic head (on the order of a few feet) and the hydraulic conductivity.

A map of the initial hydraulic conductivity values (fig. 6) was prepared using data from nine aquifer tests. In some areas, it was necessary to adjust the hydraulic conductivity that was originally estimated. The adjusted values were used during calibration of the digital model (fig. 7). The transmissivity resulting from the adjusted hydraulic conductivity values and the saturated thickness is given in plate 4.

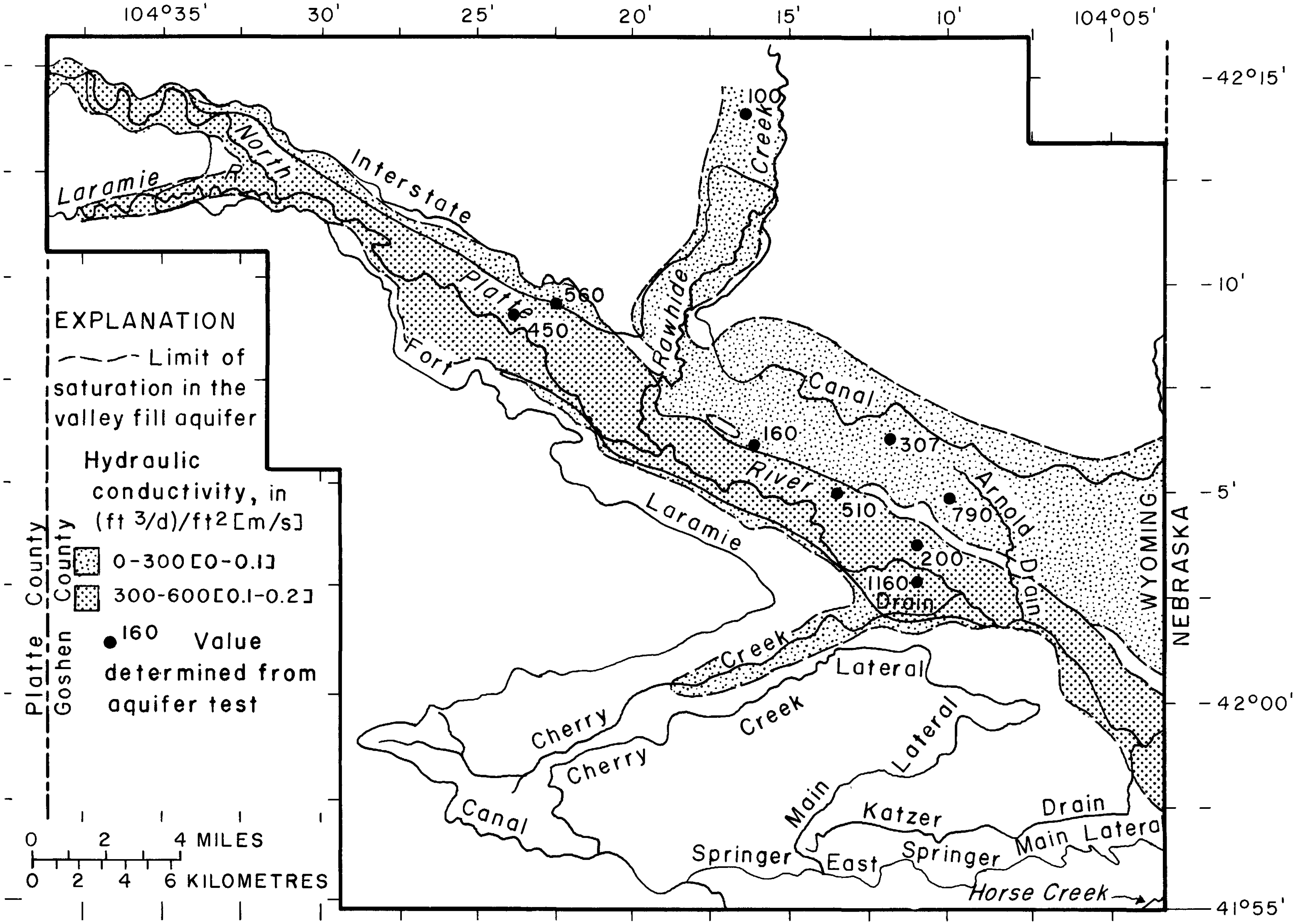

Figure 6.-Estimated hydraulic conductivity of the valley fill aquifer based on aquifer tests.

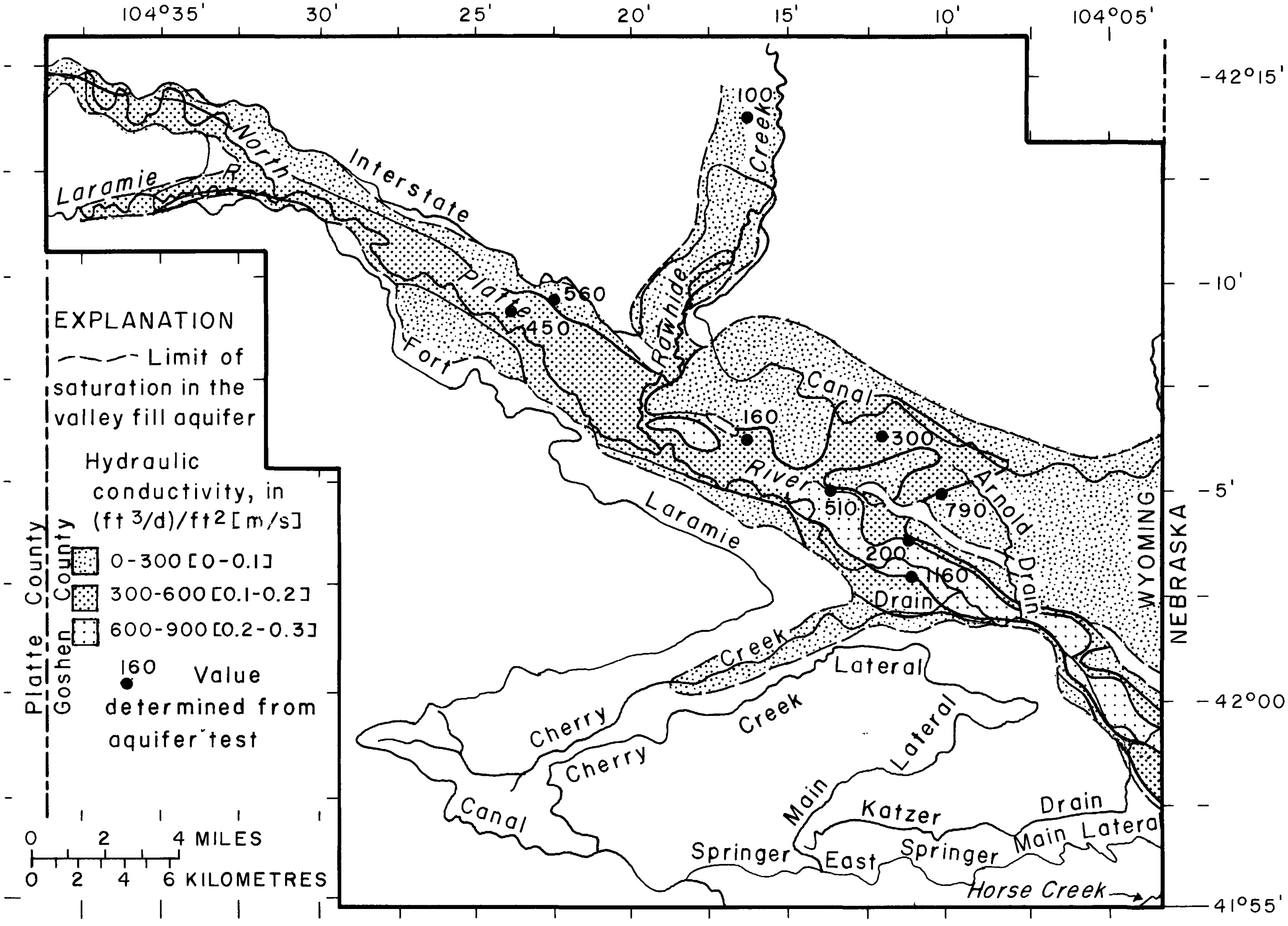

Figure 7.-Hydraulic conductivity used during calibration of the digital model.

A plot of the monthly net ground-water discharge to the North Platte River (fig. 8) is a comparison of the data in table 10 and the data generated in the model. The shape and magnitude of the curves agree quite well. After September, the discharge to the river computed in the model is less than the data given in table 10. For October through March, data in the table show that ground-water discharge (59,510 acre-feet) ($73.4 \times 10^6 m^3$) makes up about 43 percent of the outflow discharge of the North Platte River (137,950 acre-feet) ($170.1 \times 10^6 m^3$).

The net water-level changes computed in the model are within 1.5 feet (0.46 m) of the measured water-level changes more than 70 percent of the time. Some factors affecting the correlation between the computed and measured data should be noted. They are:

1. The computed data are for the entire area of the cell; whereas, the measured data are for a point within the area.

2. Many irrigation wells are utilized as observation wells and these wells are pumped intermittently.

3. Pumpage may not be evenly distributed in time and space as assumed.

4. Underflow was used to adjust drawdown in an area north of the Interstate Canal because the digital model showed that without underflow more drawdown would occur than was measured in the observation wells. (See p. 28.)

<u>Application</u>.--Because there are many conditions that might be simulated in the model, only two hypothetical conditions are simulated and described here. These conditions are: (1) Seal the Interstate Canal channel to prevent seepage from the canal, and (2) leave water in the Interstate Canal during the nonirrigation season to allow seepage from the canal all year. The model is used to simulate these conditions for 2 years and (1) predict the location(s) of the largest water-level changes and (2) predict the effect these conditions might have on the ground-water contributions to the North Platte River. All other conditions were assumed to be the same as in the period April 1970 to March 1971.

Sealing of the Interstate Canal channel, as predicted by the model, would result in lowered water levels near the canal (fig. 9) and reduced ground-water contribution to the North Platte River (fig. 10). After 2 years, the monthly rate of ground-water discharge to the river is approximately 10 percent less than would occur if the canal were not sealed.

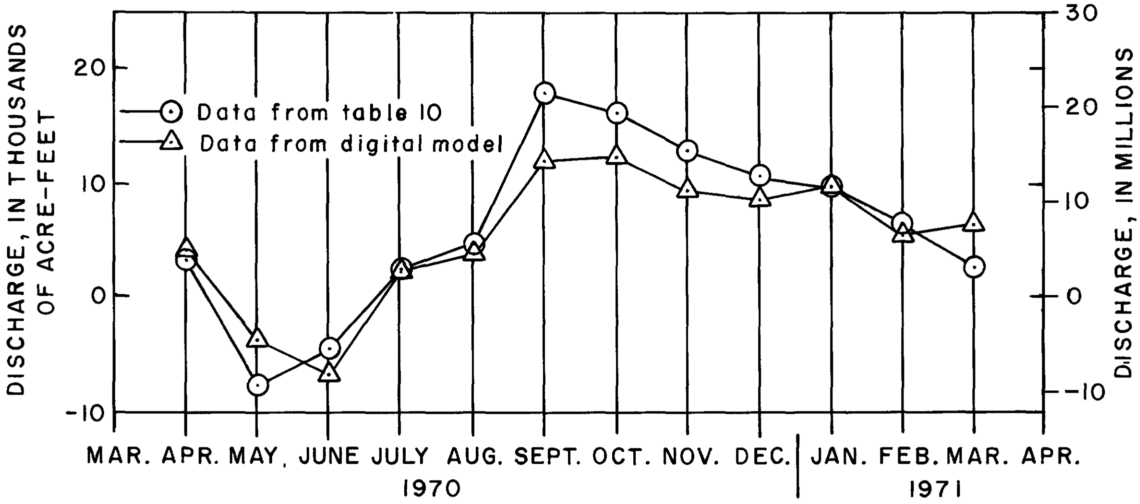

Figure 8.--Monthly net ground-water discharge to the North Platte River between Whalen Dam and the Wyoming-Nebraska State line.

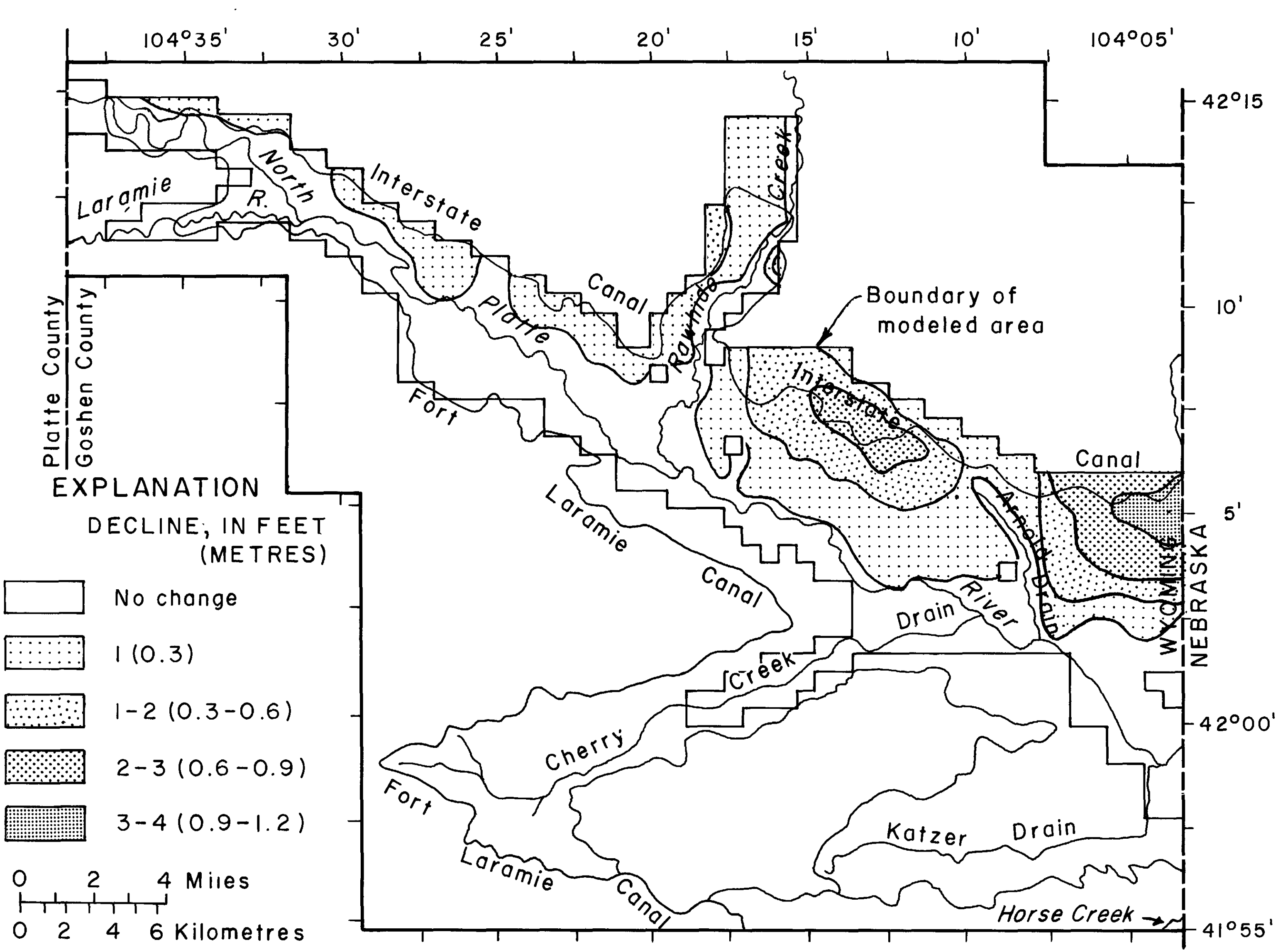

Figure 9 --Model water-level changes predicted for the second year after sealing the Interstate Canal.

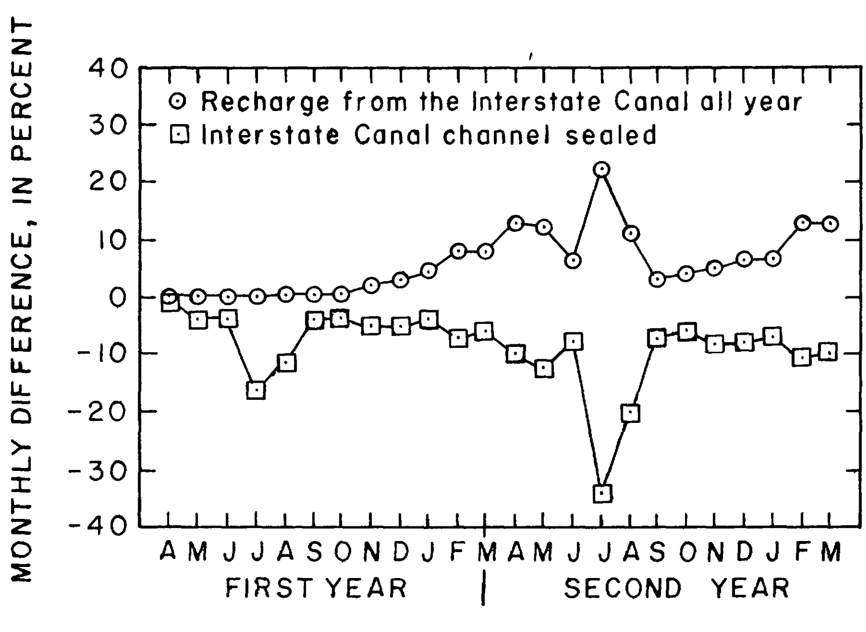

Figure 10.--Results of two conditions simulated in the digital model showing the predicted change in ground water contribution to the North Platte River. The results are given as the monthly percentage difference between the condition of no change and the condition of the simulated change.

In order to simulate recharge from the canal, it was assumed that the monthly rate of seepage from the canal during the nonirrigation season would be equal to the average monthly seepage rate that occurred during the irrigation season. This amount of recharge raises the water levels near the canal (fig. 11) and increases the monthly rate of ground-water contribution to the North Platte River by about 10 percent at the end of 2 years (fig. 9).

CONCLUSIONS

The hydrologic system of the valley fill can be simulated with a digital model. Areal distribution of the monthly net change of head in the aquifer and the monthly net change in ground-water discharge to the North Platte River computed in the model reflect the total stress on the system.

The digital model developed during this investigation can be used to predict the general effect of changes in stress that might be applied to the system and, therefore, should be used as a guide to make decisions on ground-water management. The model has been designed to simulate the general hydrologic conditions in the valley fill using the quantitative data in this report. Predictions of quantitative effects of theoretical stress changes are only as accurate as the data used to calibrate the model. Accuracy of the model could be improved by obtaining more measured data concerning evapotranspiration, acreage of each crop grown, underflow, and runoff and recharge from precipitation and irrigation. Even though estimates for these parameters are used in this report, the model can still be used to predict relative effects of stress.

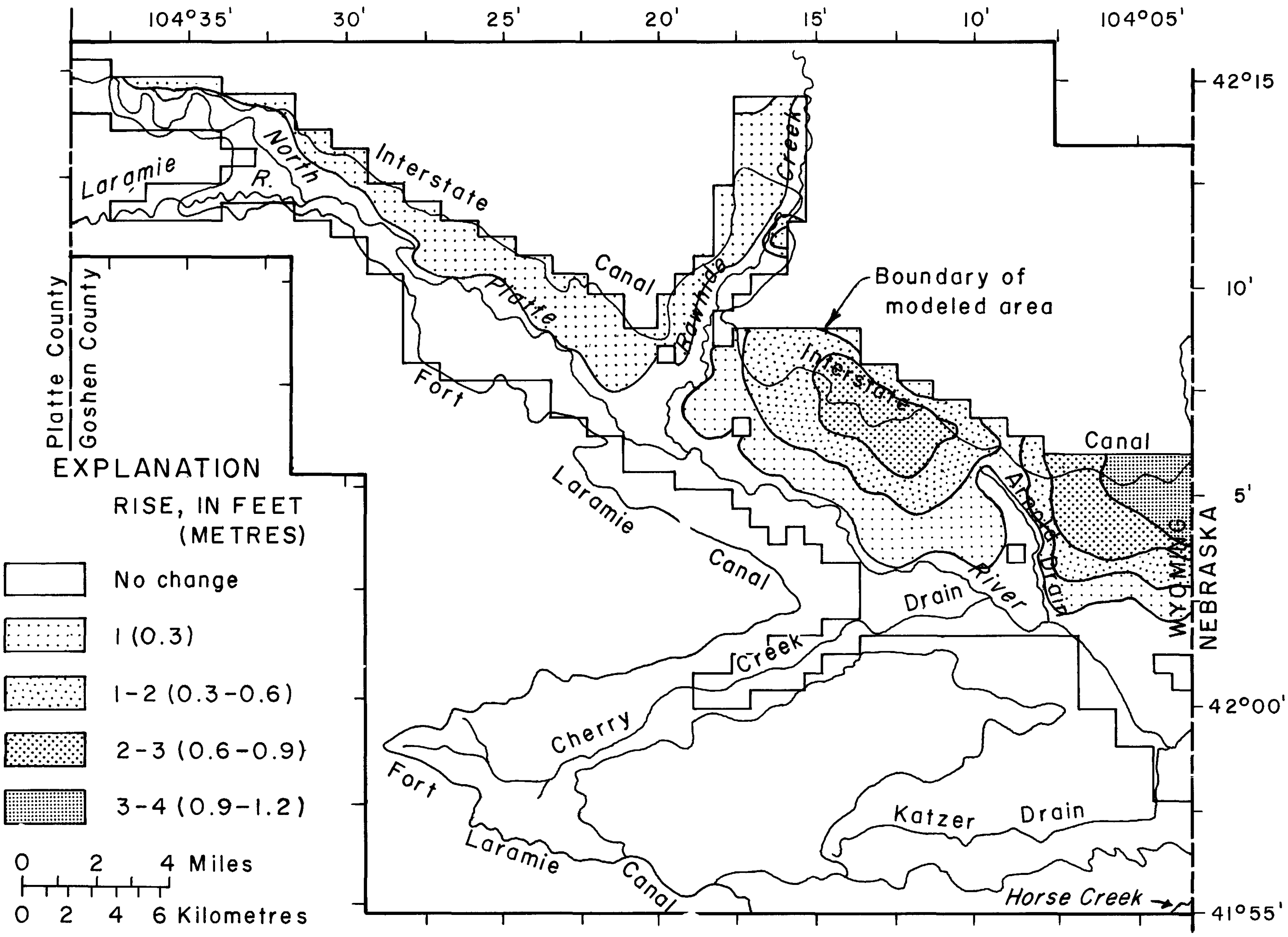

Figure 11.--Model water-level changes predicted for the second year of maintaining water in the Interstate Canal during the nonirrigation season.

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