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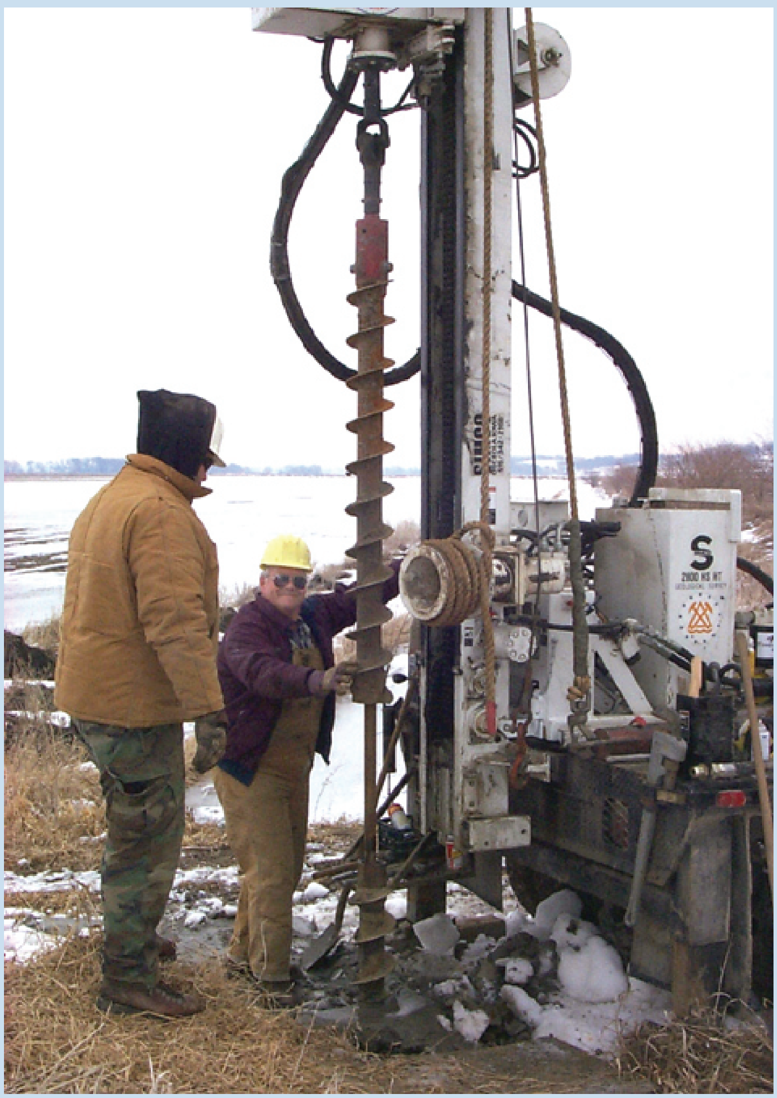
Ground Water near Pella and in Selected Parts of Jasper, Mahaska, and Marion Counties, Iowa

Water-Resources Investigations Report 02–4118



U.S. Department of the Interior
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Front cover: USGS hydrologic technician Kenneth Hedmark (facing camera) and hydrologist Michael Turco (left) are using a drill rig to install a test well in the South Skunk alluvial aquifer near Pella, Iowa (*photograph by Jim Caldwell, USGS*).

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By JAMES P. CALDWELL and ERIC M. SADORF

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Iowa City, IA
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U.S. Department of the Interior

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CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

Multiply	By	To obtain
Length		
inch (in)	2.54	centimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
millimeter (mm)	0.03937	inch
Area		
square mile (mi^2)	2.590	square kilometer
Volume		
acre-foot (acre-ft)	1,233	cubic meter
gallon (gal)	3.785	liter
million gallons (Mgal)	3,785	cubic meter
Volume per unit time (includes flow)		
cubic foot (ft^3)	28.32	liter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot per second (ft/s)	0.3048	meter per second
gallon per minute (gal/min)	0.06308	liter per second
gallon per minute per foot [(gal/min)/ft]	4.831	liter per second per meter
million gallons per day (Mgal/d)	3,785	cubic meter per day

Temperature can be converted to degrees Celsius (^oC) or degrees Fahrenheit (^oF) by the equations:

$$^oC = 5/9\ (^oF - 32)$$
$$^oF = 9/5\ (^oC)+32\ .$$

Abbreviated water-quality units used in this report: Chemical concentrations are reported in milligrams per liter (mg/L) and micrograms per liter (µg/L). A milligram per liter expresses the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water. A microgram per liter expresses the concentration of chemical constituents in solution as weight (micrograms) of solute per unit volume (liter) of water. Microsiemens per centimeter (µS/cm) at 25 degrees Celsius (^oC) expresses the capability of a unit volume of water to conduct an applied electrical current.

Sea level: In this report, "sea level" refers to the 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 the "Sea Level Datum of 1929."

Altitude: As used in this report, refers to distance above or below sea level.

Ground Water near Pella and in Selected Parts of Jasper, Mahaska, and Marion Counties, Iowa

By James P. Caldwell *and* Eric M. Sadorf

Abstract

The U.S. Geological Survey, in cooperation with the city of Pella, Iowa, conducted a study of the ground-water resources in selected parts of Jasper, Mahaska, and Marion Counties near Pella, Iowa, during 2000–01. The purpose of the study was to describe the ground-water resources in the Pella, Iowa, area.

Following a review of available hydrologic and geologic information, the study focused on investigating the alluvial deposits along the South Skunk River within a 10-mile radius of the city of Pella. Thickness, lithologic, and water-quality data for the alluvial deposits in the South Skunk River Valley were collected at selected sites from August 2000 through July 2001.

The South Skunk River alluvial aquifer near Pella consists of stratified deposits of sand and gravel of glacial and fluvial origin. The upper 15 to 20 feet of the alluvial deposits are interbedded with flood-plain clay and silt lenses and are overlain by a developed soil horizon. The alluvial aquifer is underlain by a thin (less than 50 feet thick) layer of glacial drift. Glacial drift, as it is defined in the study area, is a heterogeneous, unsorted, unstratified, unconsolidated, relatively impermeable deposit consisting of clay, sand, and gravel. The bedrock surface beneath the glacial drift consists primarily of shale and limestone of Pennsylvanian or Mississippian age. The alluvial sand and gravel deposits along the South Skunk River near Pella range from less than 30 to more than 80 feet thick. Saturated thickness of the alluvial aquifer ranges from 15 to about 70 feet.

Water-quality samples were collected from four observation wells installed in the South Skunk River alluvial aquifer in the study area. Results of the water-quality sampling show that the chemical quality of the ground water is generally similar at all of the sampling sites. All ground-water samples were low in dissolved oxygen, which resulted in high concentrations of iron and manganese and reduced forms of nitrogen.

INTRODUCTION

The city of Pella, Iowa, obtains its municipal water supply from the alluvial aquifer adjacent to the Des Moines River and a deep bedrock well completed in the Cambrian-Ordovician aquifer (locally referred to as the Jordan aquifer). A radial collector well and four vertical wells completed in the alluvium are located 3 mi south of Pella adjacent to the channel of the Des Moines River, approximately 1.5 mi south of Red Rock Dam (fig. 1). Yields from the alluvial wells are affected by the river stage (Veenstra and Kimm, Inc., written commun., 2001). These wells are classified as "ground water under the influence of surface water" by the Iowa Department of Natural Resources (IDNR). This classification requires a greater level of treatment than water from wells unaffected by streams or lakes. Pella's Cambrian-Ordovician aquifer well, adjacent to the water-treatment plant, yields water that is relatively high in dissolved solids and ammonia nitrogen.

Concerns over the quality of water from the Cambrian-Ordovician aquifer and increasing demands on water supply due to residential, commercial, and industrial development created a need for an evaluation of additional sources of public water supply in the

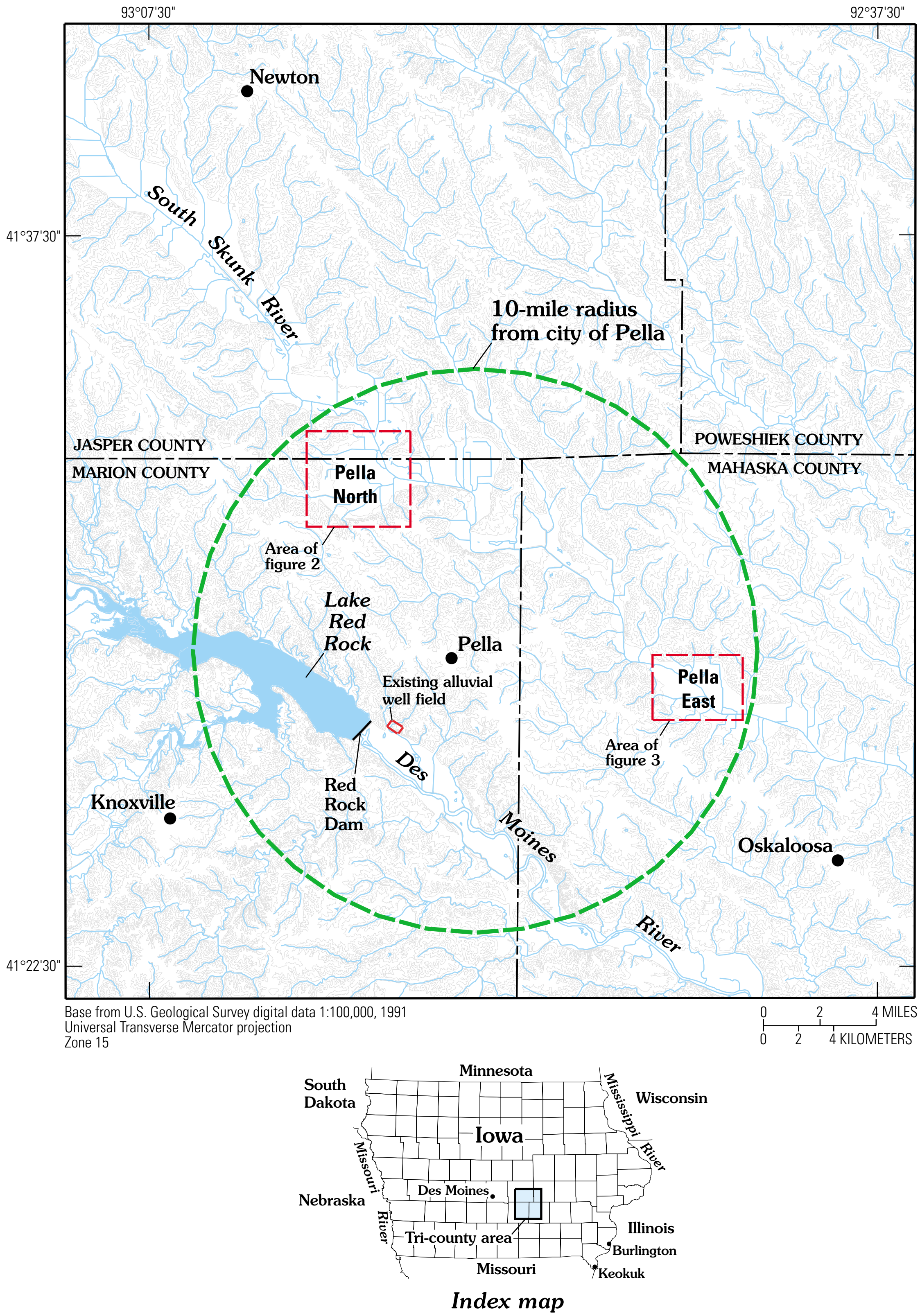

Figure 1. Location of ground-water availability study and Pella North and Pella East investigation areas near Pella, Iowa. The investigation areas lie within parts of Jasper, Mahaska, and Marion Counties.

Pella area. During 2000, municipals withdrawals from all water sources averaged 1.6 Mgal/d (Charles Keuning, Water and Wastewater Director, city of Pella, oral commun., 2000). Because the Pella metropolitan area is experiencing significant growth in population and industry, city officials estimate that water use may increase to 3.4 Mgal/d by 2010 (Veenstra and Kimm, Inc.,written commun., 2001).

To help address concerns about future sources of water supply, the U.S. Geological Survey (USGS), in cooperation with the city of Pella, conducted a study to provide information about the sources of ground water (unconsolidated and bedrock aquifers) in parts of Jasper, Mahaska, and Marion Counties, particularly in the Pella area. The objective of the study was to describe the unconsolidated and bedrock aquifers and their water quality in the Pella area using available information and data collected during 2000-01 by reconnaissance drilling, test-well installation, and water-quality sampling. The extent of the study area was limited to within a 10-mi radius of the city of Pella (fig. 1).

Purpose and Scope

The purpose of this report is to describe the results of the study of ground-water resources in parts of Jasper, Mahaska, and Marion Counties in the Pella, Iowa, area. Available hydrologic and geologic data were compiled from scientific literature and previous studies. Bedrock aquifer systems in the study area, including the Pennsylvanian, Mississippian, Silurian-Devonian, and Cambrian-Ordovician aquifers, are briefly described. The surficial (alluvial and buried-channel) aquifer systems adjacent to the Des Moines and South Skunk River alluvial valleys were the main focus of this study. Thickness, lithologic, and water-quality data for the unconsolidated alluvial deposits were collected as part of this study during 2000–01 from parts of the South Skunk River Valley north and east of Pella and are presented in this report.

Information from this study will contribute to understanding the flow systems of local and regional aquifers. Collection of hydrogeologic data from alluvial aquifers will enhance data resources needed for constructing flow models simulating interactions between ground and surface water, provide critical results needed by managers for planning and operation of public-water supplies, and provide information that is transferable to present and (or) future public-water supplies utilizing alluvial aquifer sources.

Description of Study Area

The city of Pella is in south-central Iowa between the Des Moines and South Skunk River Valleys about 35 mi southeast of Des Moines. Pella is located in the northeast corner of Marion County, about 2.5 mi northeast of the Des Moines River Valley and approximately 3 mi south of the South Skunk River Valley. Jasper County borders Marion County 8 mi north of Pella; Mahaska County borders Marion County 2.5 mi to the east of the city. The study area includes parts of Jasper, Mahaska, and Marion Counties (hereafter referred to as the "tri-county area") and is contained within a 10-mile radius of the city of Pella (fig. 1).

The study area lies within the Southern Iowa Drift Plain landform region, characterized by relatively thick glacial drift with a thick loess cover (Prior, 1991). Post-Pleistocene (Holocene) erosional processes have reshaped the glacial drift to produce level upland divides, steep hill slopes, and broad lowland valley floors. The land-surface altitude of the Des Moines and South Skunk River Valleys in this area varies from about 715 to 725 ft above sea level; land-surface altitude in adjacent upland areas is about 900 ft.

The Des Moines and South Skunk Rivers, the two major drainage systems that receive runoff from the tri-county area, originate in north-central Iowa. The Des Moines River discharges into the Mississippi River at Keokuk. Lake Red Rock, created by the construction of Red Rock Dam (1969) on the Des Moines River 2.5 mi southwest of Pella (fig. 1), has an impoundment storage capacity of 1,700,000 acre-ft. Red Rock Dam, operated by the U.S. Army Corps of Engineers (USCOE), maintains a minimum downstream flow of 300 ft^3/s (Lucey, 1991).

The confluence of the South Skunk and North Skunk Rivers is near Oskaloosa, Iowa. The Skunk River system drains to the southeast and discharges into the Mississippi River south of Burlington. Selected reaches of the South Skunk River near Pella were channelized and straightened during 1900–25 (Buchmiller, 2001). Within the study area, the South Skunk River Valley varies in width from approximately 0.5 to 3 mi.

Streamflow in the South Skunk River is measured about 25 mi upstream of the study area at a USGS streamflow-gaging station on the South Skunk River at Colfax (05471050)[1]. Annual mean daily streamflow (October 1985 through September 2000) at this site is about 622 ft^3/s. However, during October 1999 through September 2000, mean daily streamflow averaged 96.3 ft^3/s due to less-than-normal precipitation in central Iowa (Nalley and others, 2001). A USGS streamflow-gaging station, South Skunk River at Oskaloosa (05471500)[1], is located approximately 18 mi south of the study area. Annual mean daily streamflow (October 1946 through September 2000) at this site is about 1,039 ft^3/s. However, during October 1999 through September 2000, mean daily streamflow averaged 290 ft^3/s due to less-than-normal precipitation in central and south-central Iowa (Nalley and others, 2001).

Unconsolidated material of alluvial or glacial origin covers most of the tri-county area. The thickness of the unconsolidated materials in this area varies from 0 ft where the bedrock outcrops along the river valley walls to about 220 ft in areas above a buried channel that lies between the Des Moines and South Skunk River Valleys (Cagle, 1973). The valleys of these two rivers contain significant deposits of alluvial material.

The underlying bedrock in the tri-county area consists of a thick sequence of sedimentary rocks. The major bedrock aquifers within this sedimentary sequence include several water-bearing sandstone and carbonate layers within Pennsylvanian strata, and the Mississippian aquifer, the Silurian-Devonian aquifer, and the Cambrian-Ordovician aquifer system. The uppermost bedrock in the study area consists of Pennsylvanian and/or Mississippian sedimentary rocks. The geologic framework that contains these hydrogeologic units is described in table 1.

Following an initial reconnaissance investigation, this study focused on describing the water resources of the South Skunk River alluvial aquifer system. Two areas along the South Skunk River Valley, north and east of Pella, were selected for additional data collection. These two areas, referred to as the Pella North and Pella East investigation areas, were selected because of the areal extent of the South Skunk River alluvial valley at those locations (fig. 1).

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[1]Real-time stage and discharge data for these streamflow-gaging stations can be accessed on the World Wide Web at URL: http://wwwdiaiwc.cr.usgs.gov/data.html

Previous Investigations

Few comprehensive studies have been conducted to characterize all surficial and bedrock water resources in the Pella area; most have focused on the alluvial aquifer of the Des Moines River Valley and the deep Cambrian-Ordovician aquifer, known locally as the Jordan aquifer. The geology, physiography, and drainage of the tri-county area are described by Bain (1894), Miller (1900), and Williams (1904). The water resources of the tri-county area are described by Simpson and Norton (1912), Norton and others (1912), and Simpson (1912a,b). Information on the occurrence, availability, quality, and utilization of water in central, south-central, and southeast Iowa is presented in Twenter and Coble (1965), Cagle and Heinitz (1978), and Coble and Roberts (1971), respectively. The bedrock topography of central, south-central, and southeast Iowa was mapped by Hansen (1985), Cagle (1973), and Hansen (1973), respectively. Bruner and Hallberg (1987) describe the ground-water quality of the entire Skunk River Basin, particularly with regard to the occurrence of nitrate. Information about water quality and geology is available for the Mississippian aquifer (Horick and Steinhilber, 1973), the Silurian-Devonian aquifer (Horick, 1984), and the Jordan aquifer part of the Cambrian-Ordovician aquifer (Horick and Steinhilber, 1978). The recharge to, and ground-water movement in, the Jordan (Cambrian-Ordovician) aquifer was evaluated by Burkart and Buchmiller (1990). A comprehensive summary of geology and hydrologic characteristics for the major aquifers in Iowa was presented by Olcott (1992). The effects of the Red Rock Dam on the Des Moines River alluvial water-supply wells that supplied water to the city of Pella until 1973 were analyzed by W.L. Steinhilber (USGS, written commun., 1971). Lucey (1991) evaluated the ground-water flow system, geochemistry, and underseepage near Red Rock Dam near Pella. The effects of remedial grouting on the ground-water flow system at Red Rock Dam were investigated by Linhart and Schaap (2001).

Areas of the Des Moines River alluvial aquifer near the present municipal-supply wells were previously investigated by the city of Pella to determine the occurrence of sand and gravel deposits of sufficient thickness to construct additional municipal wells (Bennett and Williams, Inc., written commun., 1988, 1989). Sixteen borings (10 test borings and 6 observation wells) were installed in the Des Moines River alluvium in 1988 at selected locations within and

Table 1. Description of hydrogeologic units in south-central Iowa

Hydrogeologic unit[1]	Approximate thickness in vicinity of Pella, Iowa (feet)[1]	Age of rock unit[2]	Potential well yield (gallons per minute)	Lithology[1]
Alluvial, glacial-drift, and buried-channel aquifers	0–100	Quaternary	Less than 20 to more than 500	Sand, gravel, silt, clay, and boulders.
Pennsylvanian aquifer[3]	0–50	Pennsylvanian	Less than 10 to 100	Sandstone and limestone.
Confining unit	0–100	Pennsylvanian	Very small	Shale, sandstone, thin limestone, and coal.
Mississippian aquifer[4]	250–400	Mississippian	Less than 20 to 100	Limestone, dolomite, and shale (gypsum and anhydrite occur locally).
Confining unit	200–250	Devonian and Mississippian	Very small	Shale, siltstone, limestone, and dolomite.
Silurian-Devonian aquifer[5]	450–500	Silurian and Devonian	Less than 20 to 100	Limestone, dolomite, and shale.
Confining unit	500–550	Ordovician and Silurian	Very small	Dolomite, shale, chert, limestone, and sandstone.
Cambrian-Ordovician System Cambrian-Ordovician aquifer[6] Dresbach aquifer[7]	500–550 20–50 NA	Cambrian and Ordovician	More than 1,000 NA	Sandstone and dolomite.
Confining unit	350–550	Cambrian	Very small	Sandstone, shale, siltstone, and dolomite.
Confining unit[8]	Not determined	Precambrian	Not determined	Crystalline igneous and metamorphic rocks.

[1]Modified from Twenter and Coble (1965) and Cagle and Heinitz (1978).
[2]Age classification of rock units are those of the Iowa Department of Natural Resources, Geological Survey Bureau.
[3]Pennsylvanian aquifer and confining units are thin or absent in some locations within the tri-county area.
[4]Mississippian aquifer includes both upper and lower aquifer units.
[5]Silurian rock units are thin or absent in south-central Iowa. However, aquifer is still referred to as the "Siliurian-Devonian aquifer."
[6]Jordan aquifer is principal water-bearing strata in Cambrian-Ordovician aquifer; the St. Peter aquifer is usually cased off in water-supply wells. Thickness given is for the Jordan aquifer.
[7]Dresbach aquifer is not utilized in south-central Iowa. Hydrologic and water-quality properties are not known (NA).
[8]Precambrian confining unit hydrogeologic and water-quality properties are undetermined for tri-county area.

southeast of the present well field (Bennett and Williams, Inc., written commun., 1989). Results from this drilling indicated a relatively thin layer of alluvial sand and gravel overlying shallow bedrock. Lithologic logs from selected borings reported encountering wood, coal, and other organic debris within the aquifer (Bennett and Williams, Inc., written commun., 1989). Geologic logs from eight of the borings identified limestone as the uppermost bedrock underlying the alluvial aquifer; geologic logs from three of the borings identified shale as the uppermost bedrock; two identified sandstone, and three did not specify bedrock type. Depths to bedrock varied from 16.5 to 37.5 ft below land surface. Thickness of the sand and gravel deposits ranged from 15 to 28 ft. In 1988, the saturated thickness of the Des Moines River alluvial aquifer ranged from 11 to 22 ft, which is considered insufficient to sustain water yield rates required by the city of Pella (Veenstra and Kimm, Inc., written commun., 2001).

Within the past 10 years, the city of Pella has observed a decline in the capacity of the radial collector well and the four shallow alluvial wells that currently serve as the primary source of supply for the city. This decline in capacity is most apparent during low-flow conditions in the Des Moines River associated with dry weather or reduction of flow from the conservation pool at Red Rock Dam.

Prior to this study, few wells or test borings had been completed in the South Skunk River alluvial aquifer near Pella. Although several household and farmstead wells have been completed in the South Skunk River alluvial aquifer in this area, little geologic or hydrologic information has been reported.

Acknowledgments

The authors thank the city of Pella Water Department staff for their assistance in gathering technical information and providing field assistance. The authors also thank Ken Hedmark, Mike Turco, and Ron Kuzniar, USGS, for assistance during the installation of test borings and monitoring wells, and during data collection and compilation. Dan Christiansen, USGS, provided valuable assistance with data collection, compilation, and preparation of figures. Brian Lanning, Von Miller, Doug Schnoebelen, and Aimee Donnelly, USGS, aided in data compilation and interpretation. Mark Savoca, USGS, provided guidance in the collection and interpretation of aquifer test data. Vernon Greenwood, USCOE, provided information about the construction and maintenance of Red Rock Dam, and information about the geology and hydrology near Lake Red Rock. The authors are grateful to landowners in the Pella area who generously granted access to their property for collection of data.

GROUND WATER NEAR PELLA AND IN SELECTED PARTS OF JASPER, MAHASKA, AND MARION COUNTIES

The tri-county area is underlain by aquifers that can be divided into two main types—surficial and bedrock. Surficial aquifers in the study area consist of unconsolidated materials and can be divided into three types—alluvial, glacial drift, and buried channel. The major bedrock aquifers in the study area, which are the Pennsylvanian, Mississippian, Silurian-Devonian, and Cambrian-Ordovician aquifers, consist of sedimentary rock. Beneath the combined surficial and sedimentary rock sequences lie Precambrian crystalline igneous and metamorphic rocks, referred to as the basement complex. The basement complex is not believed to contain water in south-central Iowa and, therefore, is considered to be the base of the ground-water reservoir (Cagle and Heinitz, 1978).

Ground-water-yield characteristics and water quality varies both between the aquifers and within each aquifer. Generally, well yield is directly proportional to the thickness of the aquifer. Alluvial aquifers will yield more water to wells on a sustained basis where the deposits are exposed or near the surface and can be recharged by infiltration of precipitation or by surface water. Glacial-drift and buried-channel aquifers can have moderately high yields but usually cannot sustain high pumping rates (greater than 300 gal/min) because recharge to these deeper aquifers is limited by the water-transmitting characteristics of the overlying materials (Buchmiller, 2001).

In areas where carbonate (limestone and dolomite) bedrock is near the land surface and is not covered by confining units, the rock may be highly fractured due to weathering, erosion, and glacial loading and unloading processes prior to burial by younger geologic materials. Fractures in bedrock aquifers enhance permeability and improve water-transmitting characteristics to wells.

Water quality also affects whether ground water can be used for human consumption. Dissolved solids and naturally occurring minerals, such as sulfate, limit the use of ground water in some areas because of drinking-water regulations, aesthetic reasons, or treatment costs.

The aquifers that can consistently yield sufficient quantities and that may have acceptable water quality for water-supply development in the Pella area include alluvial aquifers and the Cambrian-Ordovician aquifer system. The Mississippian aquifer and the Silurian-Devonian aquifer may be capable of yielding sufficient quantities for development as a ground-water resource, but the variable chemical quality of the water from these aquifers generally precludes use for a water supply. In south-central Iowa, water from glacial-drift and buried-channel aquifers is used mainly by private, rural wells.

Surficial Aquifers

The surficial aquifers in the tri-county area are the Quaternary water-bearing sand and gravel deposits that lie between the land surface and the bedrock surface, except for a few areas of bedrock outcrops. These widespread, but irregular, deposits are divided into three classifications (alluvial, glacial drift, and buried channel) on the basis of areal and vertical distribution and water-bearing characteristics.

Alluvial Aquifers

Alluvial aquifers are the shallowest and therefore most readily available sources of potential ground-water supply. Alluvial aquifers are contained in unconsolidated materials deposited by fluvial processes within the stream valleys. In the tri-county area, alluvial aquifers consist mostly of sand and gravel. Recharge to the alluvial aquifers is by infiltration of precipitation, stream seepage, and seepage from underlying glacial-drift or bedrock aquifers (W.L. Steinhilber, USGS written commun., 1971).

Available information on the alluvial deposits in the Des Moines River Valley near Pella is limited to the areas near Red Rock Dam and the current (2002) and abandoned (1973) city of Pella well fields. In the vicinity of the Red Rock Dam on the Des Moines River (fig. 1), many test holes and observation wells were completed in and through the alluvial deposits by the USCOE as part of an exploratory and continual monitoring program to assess the geologic, hydrologic, and geochemical conditions at the dam and reservoir site (W.L. Steinhilber, USGS, written commun., 1971; Lucey, 1991; Linhart and Schaap, 1999). Information also is available for the current and abandoned Pella municipal well fields on the east bank of the Des Moines River channel, within 0.25 to 1.5 mi downstream of Red Rock Dam (Ranney Water Systems, written commun., 1967; W.L. Steinhilber, USGS, written commun., 1971; Bennett and Williams, Inc., written commun., 1989). The thickness and lithology of the Des Moines River alluvial deposits near Pella are described in the "Previous Investigations" section of this report.

Prior to this study, very little data had been collected pertaining to the South Skunk River alluvial aquifer near Pella. Data collected during this study show that the South Skunk alluvial aquifer near Pella consists of stratified deposits of sand and gravel of glacial and fluvial origin. The thickness and lithology of the South Skunk River alluvial deposits in the Pella North and Pella East investigation areas are described in a following section of this report.

Most of the tri-county area is located in the south-central part of the State. Possible yields for alluvial wells in south-central Iowa range from 5 to 500 gal/min (Cagle and Heinitz, 1978). Available well yields for the Des Moines River alluvial aquifer in the study area (five wells) range from 150 to 530 gal/min (Iowa Department of Natural Resources, 2001).

Alluvial aquifers yield the least mineralized water of all ground-water sources in south-central Iowa (Cagle and Heinitz, 1978). The water quality of the alluvial aquifers reflects the characteristics of water from wells that are completed in sand and gravel consisting mostly of siliceous materials of low solubility. Hardness (as $CaCO_3$) averages about 400 mg/L, and alkalinity (as $CaCO_3$) averages about 250 mg/L (Twenter and Coble, 1965; Cagle and Heinitz, 1978). Dissolved solids concentration usually is less than 500 mg/L. Majors ions are calcium and bicarbonate, but sulfate and sodium also are important constituents.

Glacial-Drift Aquifers

Glacial drift underlies the alluvial aquifers within the stream valleys and is exposed in the upland areas throughout most of the tri-county area. The maximum thickness of glacial drift in south-central Iowa is about 430 ft (Cagle and Heinitz, 1978), but in the tri-county area, the maximum thickness is approximately 200 ft. The glacial-drift aquifers occur in discontinuous sand and gravel lenses contained within the clay-rich matrix of the drift deposits. These lenses of aquifer material seldom exceed 5 ft in thickness and are local in occurrence (Cagle and Heinitz, 1978). The specific capacity (yield per unit of drawdown) for glacial-drift wells in the tri-county area ranges from 0.3 to 5 (gal/min)/ft (Iowa Department of Natural Resources, 2001). Possible yields for wells completed in the glacial-drift aquifer in south-central Iowa range from 1 to 5 gal/min (Cagle and Heinitz, 1978).

Water from glacial-drift aquifers in south-central Iowa generally is very hard and may contain undesirable concentrations of dissolved solids, sulfate, nitrate, and iron (Cagle and Heinitz, 1978). The water quality in glacial-drift aquifers varies significantly with depth, with larger concentrations of hardness ($CaCO_3$), dissolved solids, sodium, sulfate, and iron present in the deeper sand and gravel lenses. However, nitrate (NO_3) concentrations vary inversely with depth due to the infiltration of nitrate-bearing surface water into the shallower aquifer units. Hardness concentrations average 539 mg/L ($CaCO_3$), dissolved solids concentrations average about 970 mg/L, sulfate concentrations average 336 mg/L, nitrate concentrations average about 60 mg/L (NO_3), and iron concentrations average 2,000 µg/L (Cagle and Heinitz, 1978).

Buried-Channel Aquifers

The sand and gravel comprising buried-channel aquifers were deposited in glacial drift or bedrock valleys, which were covered by later glacial deposits. Buried-channel aquifers can, but do not always, coincide with present stream valleys and are usually concealed by surficial deposits (Thompson and Kemmis, 1990; Olcott, 1992). Water-bearing deposits in the buried-channel aquifers tend to be more widely distributed than the water-bearing lenses of glacial-drift aquifers. A buried-channel aquifer was mapped in the tri-county area between the South Skunk and Des Moines River Valleys (Hansen, 1985). Wells completed in this aquifer range in depth from 200 to 215 ft. The thickness of the water-bearing gravel deposits ranges from 0 to 20 ft. Possible yields for wells completed in the buried-channel aquifers in south-central Iowa range from 5 to 25 gal/min (Cagle and Heinitz, 1978); the specific capacity for these wells range from 0.09 to 7.14 (gal/min)/ft (Iowa Department of Natural Resources, 2001).

Buried-channel aquifers in south-central Iowa yield hard water that is highly mineralized and similar to the chemical composition of the deep glacial-drift aquifers (Cagle and Heinitz, 1978). Hardness concentrations average 868 mg/L ($CaCO_3$), dissolved solids concentrations average about 2,350 mg/L, sulfate concentrations average 1,254 mg/L, nitrate concentrations average 6.7 mg/L as NO_3, and iron concentrations average 3,400 μg/L (Cagle and Heinitz, 1978).

Bedrock Aquifers

The water-bearing characteristics of the consolidated sedimentary rocks within the tri-county area are highly variable. The bedrock units that yield water to wells, in order of increasing depth below land surface, are the Pennsylvanian aquifer, the Mississippian aquifer, the Silurian-Devonian aquifer, and the Cambrian-Ordovician aquifer.

High dissolved mineral concentrations limit the use of water from bedrock aquifers in most parts of south-central Iowa and are a deterrent to more extensive development of these resources (Cagle and Heinitz, 1978). The natural chemical quality of water from the principal bedrock aquifers in south-central Iowa is highly variable and is affected primarily by the mineralogy of aquifer materials and the length of time that the water is in contact with these minerals (Olcott, 1992). Because chemical concentrations tend to increase along ground-water flow paths, ground water in outcrop and recharge areas is the least mineralized. Ground water in deep, confined aquifers where the water movement is slow tends to be the most mineralized (Cagle and Heinitz, 1978; Buchmiller, 2001).

Of the bedrock resources described for this study, only the Cambrian-Ordovician aquifer is considered capable of yielding large quantities of potable water suitable for public water-supply wells (Veenstra and Kimm, Inc., written commun., 2001). However, the expense of constructing a water-supply well in this deep aquifer (greater than 2,000 ft below surface), coupled with high maintenance, operation, and water-treatment costs due to high mineralization of the water, may limit development of this aquifer (Veenstra and Kimm, Inc., written commun., 2001).

Pennsylvanian Aquifer

Consolidated sedimentary rocks of Pennsylvanian age form the bedrock surface in much of the tri-county area. These stratified deposits consist primarily of shale and thin, discontinuous layers of sandstone, limestone, siltstone, and coal. Several Pennsylvanian limestone and sandstone units contain aquifers but are limited in areal extent and thickness. Although little information is available for the Pennsylvanian aquifer in the tri-county area, estimated yields from this aquifer in most places in south-central Iowa are less than 25 gal/min, typically 3 to 10 gal/min, with a few areas yielding 100 gal/min (Cagle and Heinitz, 1978).

In most areas of south-central Iowa, the Pennsylvanian aquifer yields water that contains undesirable concentrations of minerals. Chemical analysis of water samples collected from this aquifer shows the following average concentrations of constituents: hardness (869 mg/L as $CaCO_3$), dissolved solids (4,531 mg/L), sulfate (1,088 mg/L), nitrate (3.5 mg/L as NO_3), and iron (3,200 μg/L) (Cagle and Heinitz, 1978).

Pennsylvanian strata form a regional confining unit that, in some areas, separate overlying unconsolidated materials from the Mississippian aquifer. In some localized areas, a limited water supply can be developed in bedrock of Pennsylvanian age, but excess mineralization and low yield preclude large-scale development as a water supply.

Mississippian Aquifer

Mississippian strata underlie the entire tri-county area and in some places form the bedrock surface. The Mississippian aquifer includes two main aquifers, locally referred to as the upper and lower aquifers, which occur within the limestone, dolomite, and localized interbeds of gypsum and anhydrite. The presence of these evaporite minerals may increase dissolved solids and sulfate concentrations in water from this source.

Well yields are highest in areas where the Mississippian strata form the bedrock surface and aquifer recharge is from overlying surficial aquifers (Cagle and Heinitz, 1978). In the tri-county area, well yields range from 5 to 20 gal/min where Mississippian strata are overlain by Pennsylvanian strata and from 5 to 60 gal/min where the Mississippian strata form the bedrock surface. Specific capacities calculated for 165 wells in south-central Iowa indicate a median value of 0.15 (gal/min)/ft for the upper, and 0.10 (gal/min)/ft for the lower aquifer (Cagle and Heinitz, 1978).

Within the tri-county area, the quality of water from the Mississippian aquifer is highly variable and quite mineralized, but water of acceptable quality may be available from both the upper and lower aquifers in limited areas of Marion County near Pella. In Marion County, the best quality water occurs in isolated areas where the Pennsylvanian bedrock has been eroded and the Mississippian strata are the bedrock surface (Cagle and Heinitz, 1978).

Within these isolated areas, the average concentration of hardness is 449 mg/L ($CaCO_3$), dissolved solids is 674 mg/L, sulfate is 217 mg/L, nitrate ranges (three samples only) from 0.10 to 4.3 mg/L as NO_3, and iron is 2,200 μg/L. In the remainder of the tri-county area, water from the Mississippian aquifer system is very highly mineralized. The average concentration of hardness is 923 mg/L ($CaCO_3$), dissolved solids is 4,274 mg/L, sulfate is 2,385 mg/L, nitrate is 8.4 mg/L as NO_3, and iron is 7,600 μg/L (Cagle and Heinitz, 1978). In localized areas near Pella, a limited water supply could be developed from the Mississippian aquifer; however, the likelihood of excess mineralization and low yield probably preclude large-scale development of this aquifer.

Silurian-Devonian Aquifer

The Silurian-Devonian aquifer of Iowa is contained in a thick succession of carbonate (limestone and dolomite) rocks of Silurian and Devonian age. Although the carbonate units that compose the Silurian-Devonian aquifer in Iowa are distinct geologic entities, it is common to treat them as one hydrolgeologic unit because of their hydraulic connection (Horick, 1984). Within the tri-county area, however, Silurian rocks are thin or absent. In the study area, the Silurian-Devonian aquifer mainly occurs within Devonian-age carbonate rocks. To remain consistent with established geologic nomenclature, the term "Silurian-Devonian aquifer" is used in this respect despite the localized absence of Silurian-age rocks.

The Silurian-Devonian aquifer is separated from the overlying Mississippian aquifer by a thick confining unit, which usually is shale. Although composed primarily of limestone and dolomite, the Silurian-Devonian aquifer also may contain evaporite minerals such as gypsum and anhydrite. The typical thickness of the Silurian-Devonian aquifer in the tri-county area is about 500 ft (Twenter and Coble, 1965; Coble and Roberts, 1971; Cagle and Heinitz, 1978).

Few wells have been completed in the Silurian-Devonian aquifer in south-central Iowa. Projected well yields range from 20 to 100 gal/min in this area (Cagle and Heinitz, 1978). Evaporite minerals that occur locally in the Silurian-Devonian strata have a major effect on water quality. Where these minerals occur, degradation of water quality can be caused by high concentrations of sulfate, sodium, potassium, and chloride. Dissolved solids concentrations in this aquifer are in excess of 5,000 mg/L throughout most of the tri-county area (Twenter and Coble, 1965; Coble and Roberts, 1971; Cagle and Heinitz, 1978; Olcott, 1992). The naturally occurring poor water quality and low yield limit the use of water from the Silurian-Devonian aquifer within the tri-county area.

Cambrian-Ordovician Aquifer System

The Cambrian-Ordovician aquifer system is a complex multi-aquifer system with individual aquifers separated by leaky confining units. In south-central Iowa, the aquifer system consists of an upper unit, the Cambrian-Ordovician aquifer (as differentiated from the Cambrian-Ordovician aquifer system), and a lower part, the Dresbach aquifer. The two aquifer units are separated by a thick confining unit of Cambrian-age strata (Olcott, 1992; Turco, 1999). The Cambrian-Ordovician aquifer is separated from the overlying Silurian-Devonian aquifer by a thick Ordovician shale and dolomite sequence.

The principal source of ground water to wells within the Cambrian-Ordovician aquifer system is the Cambrian-Ordovician aquifer (Turco, 1999). The Cambrian-Ordovician aquifer occurs within a dolomite and sandstone sequence; two sandstone units that function as aquifers are part of this hydrogeologic unit. The upper sandstone unit, which composes the St. Peter aquifer, is very friable and is usually cased off in water-supply wells in south-central Iowa (Cagle and Heinitz, 1978; Turco, 1999; Bill Bunker, Iowa Geological Survey Bureau, oral commun., 2002). The lower sandstone unit, which composes the Jordan aquifer, is the principal water-bearing unit and accounts for the high yields attributed to the Cambrian-Ordovician aquifer. In the study area, the depth to the top of the Jordan aquifer ranges from 2,045 to 2,220 ft below the land surface.

In south-central Iowa, hydrologic data are lacking for the Dresbach aquifer, the lower part of the Cambrian-Ordovician aquifer system (Cagle and Heinitz, 1978). Because the depth to the top of the Dresbach aquifer is greater than 2,200 ft below land surface in the Pella area and the hydrologic and water-quality properties are unknown, the Dresbach aquifer was not considered in this study.

The Cambrian-Ordovician aquifer, with potential well yields in excess of 1,000 gal/min, has the highest yield of any of the aquifers in the study area (Cagle and Heinitz, 1978). In the eastern one-third of south-central Iowa, which contains most of the tri-county area, the Cambrian-Ordovician aquifer yields fair quality water. Dissolved solids concentrations average 1,000 mg/L, sulfate concentrations average 285 mg/L, and chloride concentrations average 88 mg/L (Cagle and Heinitz, 1978).

DESCRIPTION OF SOUTH SKUNK RIVER ALLUVIAL DEPOSITS NEAR PELLA

The alluvial deposits associated with the South Skunk River Valley near Pella consist of stratified sand and gravel deposits that are the result of post-Pleistocene (Holocene) valley fill and modern fluvial processes. The upper 12 to 20 ft of the alluvial deposits are interbedded with silt, very fine sand, and clay lenses and are overlain by a developed, organic-rich soil horizon. The alluvial deposits beneath this thin veneer of fine-grained materials generally become coarser with depth.

Although all the unconsolidated materials described in available geologic logs could be expected to yield water, only those materials that are described as having a particle size equal to or larger than medium-grained sand (approximately 0.25 to 0.50 mm in diameter) are considered to be the alluvial aquifer for the purposes of this report. Therefore, the thickness of the alluvial aquifer, with respect to its water-resource development potential, is defined as the interval thickness of sand and gravel below the base of the surficial flood-plain silt, clay, and soil layer and above the top of the underlying glacial drift.

Collection of Test-Hole and Observation-Well Data

Test holes and observation wells were installed by the USGS to collect new geologic and hydrologic information for the unconsolidated deposits in the Pella North and Pella East investigation areas. Following completion of the reconnaissance test-boring activities, observation wells for measuring water levels, determining hydraulic characteristics, and collecting water-quality samples were constructed adjacent to selected test holes. The latitude and longitude of the observation wells and test holes were determined by a global positioning system (GPS). Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD83).

A total of 13 test holes, with an average depth of 64.5 ft, were drilled by USGS in 2000 in the Pella North and Pella East areas (figs. 2 and 3). All test holes were drilled with 4-in. outside-diameter (OD) solid-stem augers. Borings were advanced to bit refusal, defined by slow penetration rate and high drill-bit pressure, or to the depth limits (approximately 85 ft) of the drill rig being used. Samples of auger cuttings were collected at major lithologic changes from the auger flights as they were withdrawn from the borehole after reaching total depth, a technique known as "profile augering."

The test holes indicate that the thickness of the alluvial deposits ranges from about 55 to more than 80 ft. The upper 15 to 20 ft of the alluvial deposits are interbedded with flood-plain clay and silt lenses and are overlain by a developed organic-rich soil horizon. The deposits composing the alluvial aquifer are a fining-upward sequence of sand and gravel that does not appear to have significant interbedding of clay and silt lenses beneath a depth of about 20 ft. Although the

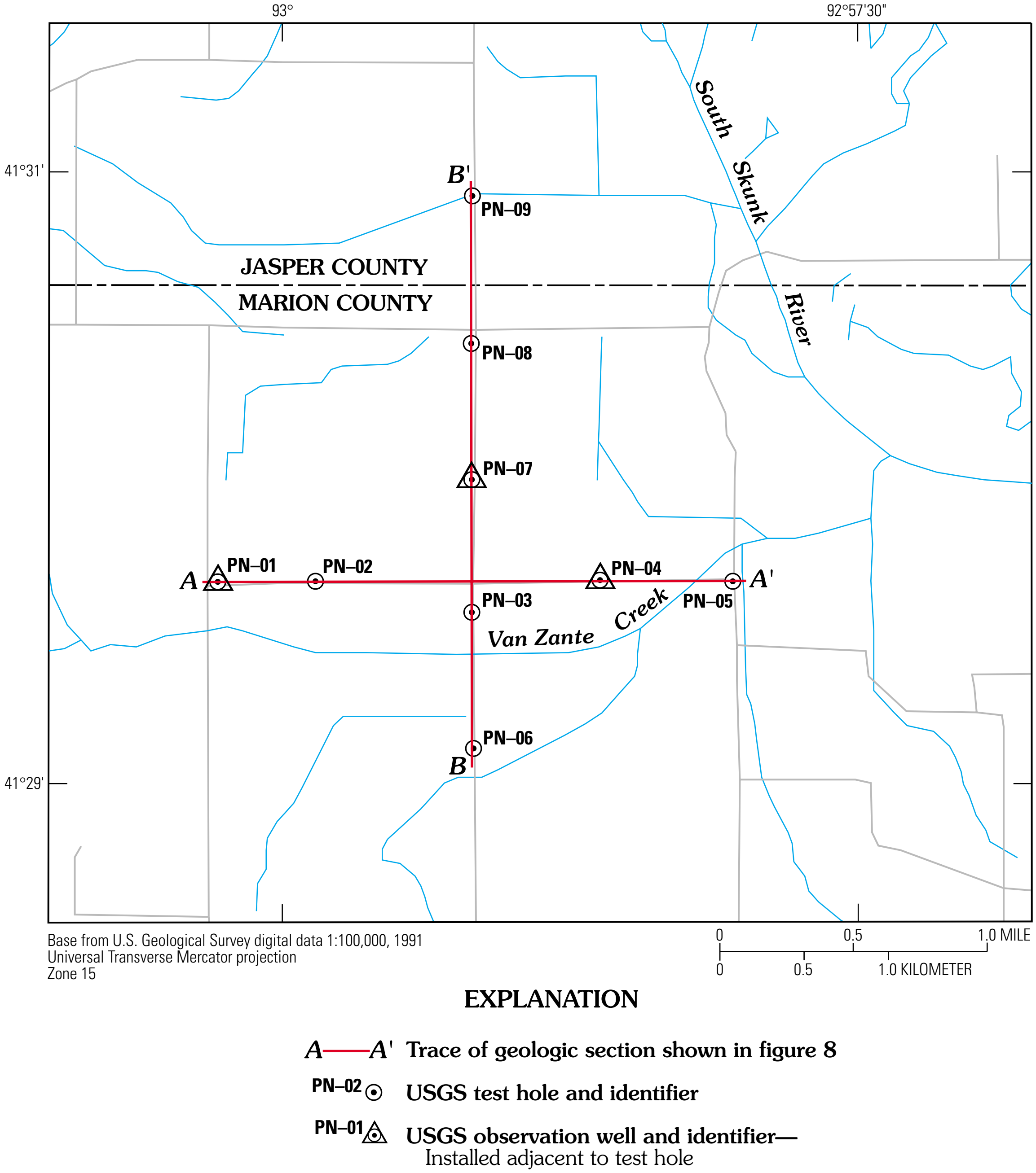


Figure 2. Location of data-collection sites at Pella North investigation area, South Skunk River alluvial valley near Pella, Iowa.

mineralogy of the alluvial aquifer was not examined in detail, the principal mineral constituents appear to be mostly quartz, with minor limestone and lithic fragments. Wood and organic debris frequently were observed in well cuttings. USGS boring logs (table 2) indicate the alluvium is underlain by clay-rich glacial drift.

After reviewing the stratigraphic information from the test holes, observation wells were constructed at three locations within the Pella North area (fig. 2) and at one location in the Pella East area (fig. 3). The four observation wells were constructed adjacent to the original test holes to maintain subsurface control. Borings for the observation wells were advanced using 3.25-in. inside-diameter (ID) continuous-flight hollow-stem augers. Samples of drill cuttings returned to land surface during drilling were collected at major lithologic changes, as were samples collected from the

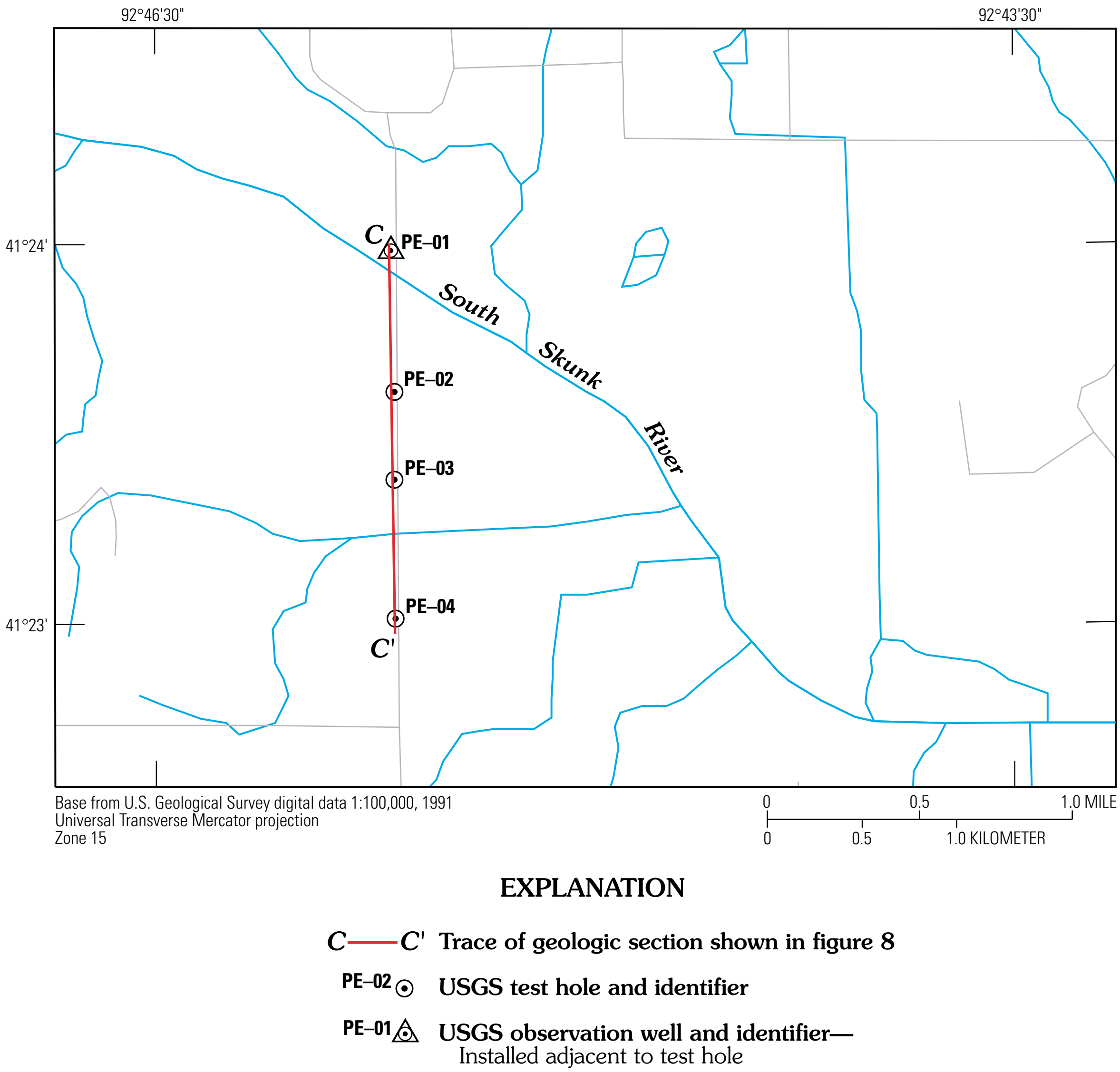


Figure 3. Location of data-collection sites at Pella East investigation area, South Skunk River alluvial valley near Pella, Iowa.

auger flights as previously described for test-hole drilling. Observation wells were constructed by lowering 2-in. inside-diameter (ID) schedule-40, flush-threaded polyvinyl chloride (PVC) well casing, equipped with 5-ft, 0.010-in. slot-size well screens, into the annulus of the hollow-stem auger assembly. Well screens were placed within an interval of the aquifer that consisted of medium or larger grained-sized materials. The annular space (7.25-in. nominal borehole size) around the screen and riser was allowed to fill with native materials during withdrawal of the hollow-stem auger assembly, providing a "natural" filter pack. The upper 4 ft of the annular space was filled with bentonite clay to prevent surface runoff from entering the borehole. To minimize the turbidity of the water, wells were developed by pumping until the discharge water was clear to remove fine-grained sand and silt from the natural filter pack. Well depths ranged from 47.5 to 57.5 ft below land surface. Test-hole locations and associated geologic information are listed in table 2.

Thickness and Lithology

Descriptive logs of the 13 USGS test holes drilled in the two investigation areas (table 2) indicate clay-rich glacial drift underlies the sand and gravel of the alluvial aquifer at these sites. The thickness of the glacial drift in the investigation areas is unknown because

Table 2. Description of drilled test holes and geologic information used in study of ground water near Pella, Iowa

Test-hole identifier[1] (figs. 2 and 3)	Location land net[2] (latitude, longitude)	Geologic unit[3]	Depth below land surface[4] (feet)	Drillers log/cuttings description (blue background indicates alluvial aquifer interval)
			Pella North investigation area	
PN–01	41°29'39.8" 93°00'17.2"	Qa	0–5	Dark brown silt, clayey.
			5–20	Light brown-gray silt.
			20–35	Light brown to gray sand, silty.
			35–82	Light brown-gray sand, coarsening downward. Lenses of small to coarse gravel appear at 35 feet and are present to total depth. Lenses of fine sand and silt are interspersed in sandy alluvium.
		Qag	82 (TD)	Clay, glacial drift.
PN–02	41°29'39.7" 92°59'51.6"	Qa	0–5	Dark brown silt, clayey.
			5–20	Light brown to gray silt.
			20–60	Tan-brown-gray sand, coarsening downward. Dark organic particulate and thin lenses of clay and silt are present throughout sandy alluvium. Lenses of small to coarse gravel appear at 35 feet and are present to total depth. Lenses of fine sand and silt are interspersed in sandy alluvium.
		Qag	60–62	Clay, glacial drift.
			62 (TD)	Clay, glacial drift.
PN–03	41°29'33.6" 92°59'10.8"	Qa	0–5	Dark brown silt, clayey.
			5–25	Light-medium brown to gray silt.
			25–60	Tan-brown-gray sand, coarsening downward. Lenses of small to coarse gravel appear at 35 feet and are present to total depth. Lenses of fine sand and silt are interspersed in sandy alluvium.
		Qag	60–62	Clay, glacial drift.
			62 (TD)	Clay, glacial drift.
PN–04	41°29'39.9" 92°58'37.5"	Qa	0–5	Dark brown silt.
			5–25	Medium brown to gray silt, clayey.
			25–57	Tan-brown-gray sand, coarsening downward. Lenses of small to coarse gravel appear at 35 feet and are present to total depth. Lenses of fine sand and silt are interspersed in sandy alluvium.
		Qag	57 (TD)	Clay, glacial drift.
PN–05	41°29'39.6" 92°58'02.9"	Qa	0–8	Dark brown silt.
			8–27	Medium brown to gray silt, sandy.
			27–56	Medium brown to gray sand, coarsening downward. Lenses of small to coarse gravel appear at 35 feet and are present to total depth. Lenses of fine sand and silt are interspersed in sandy alluvium.
		Qag	56 (TD)	Clay, glacial drift.
PN–06	41°29'06.9" 92°59'10.5"	Qa	0–12	Dark brown silt.
			12–52	Medium brown to gray silt with occasional lenses of fine sand.
			52 (TD)	Gray silt.

Table 2. Description of drilled test holes and geologic information used in study of ground water near Pella, Iowa

Test-hole identifier[1] (figs. 2 and 3)	Location land net[2] (latitude, longitude)	Geologic unit[3]	Depth below land surface[4] (feet)	Drillers log/cuttings description (blue background indicates alluvial aquifer interval)
		Pella North investigation area—Continued		
PN–07	41°29'56.6" 92°59'10.9"	Qa	0–5	Dark brown silt.
			5–15	Medium brown to gray silt, sandy.
			15–71	Medium brown to gray sand, coarsening downward. Lenses of small to coarse gravel appear at 20 feet and are present to total depth. Lenses of fine sand and silt are interspersed in sandy alluvium.
		Qag	71 (TD)	Clay, glacial drift.
PN–08	41°30'26.3" 92°59'11.1"	Qa	0–5	Dark brown silt.
			5–52	Medium brown to gray sand, coarsening downward. Lenses of small to coarse gravel appear at 40 feet and are present to total depth. Lenses of fine sand and silt are interspersed in sandy alluvium.
		Qag	52–62 (TD)	Clay, glacial drift.
PN–09	41°30'55.3" 92°59'10.7"	Qa	0–5	Dark brown silt.
			5–25	Medium brown to gray silt, sandy.
			25–52	Medium brown to gray sand, coarsening downward. Lenses of small to coarse gravel appear at 30 feet and are present to total depth. Lenses of fine sand and silt are interspersed in sandy alluvium.
		Qag	52 (TD)	Clay, glacial drift.
		Pella East investigation area		
PE–01	41°23'58.7" 92°45'40.5"	Qa	0–5	Dark brown-black sandy silt, clayey.
			5–12	Medium brown sandy silt.
			12–68	Light brown-gray sand, coarsening downward. Lenses of small to coarse gravel appear at 56 feet and are present to total depth.
		ND[5]	68–70	Very coarse gravel or weathered bedrock, slow penetration rate.
			70 (TD)	Very coarse gravel or weathered bedrock.
PE–02	41°23'36.5" 92°45'39.8"	Qa	0–5	Dark brown-black sandy silt, clayey.
			5–12	Medium brown sandy silt.
			12–57	Tan-brown-gray sand, coarsening downward. Dark organic particulate and thin lenses of clay and silt are present throughout sandy alluvium. Lenses of coarse to very coarse sand present from 42–57 feet.
		Qag	57–72	Clay, glacial drift.
			72 (TD)	Clay, glacial drift.
PE–03	41°23'22.8" 92°45'39.8"	Qa	0–5	Dark brown-black silt.
			5–15	Medium-rusty brown sandy silt.
			15–45	Rusty brown very fine sand, becoming gradationally coarser to very coarse at 40 feet.
		Qag	45–85	Medium-dark gray clay, glacial drift. Very dense, dry.
			85 (TD)	Clay, glacial drift.
PE–04	41°23'00.6" 92°45'39.5"	Qa	0–5	Dark brown silt, clayey.
			5–52.5 (TD)	Light-medium brown to gray fine sand becoming gradationally coarser with depth. Light gray, medium sand.

[1]Test holes PN–01 to PN–09, and PE–01 to PE–04 were drilled by U.S. Geological Survey during October 30–November 8, 2000.
[2]Location is given by latitude (top sequence) and longitude (bottom sequence).
[3]Qa = Quaternary-age alluvium; Qag=Quaternary-age alluvium and glacial drift.
[4]TD = total depth.
[5]ND = not determined.

it was fully penetrated in only one of the borings. However, published bedrock-altitude maps of central and south-central Iowa indicate that the glacial-drift thickness is less than 50 ft in the South Skunk River alluvial valley (Hansen, 1972, 1973, 1985; Cagle, 1973). Depth to the top of the glacial drift in boreholes and wells ranged from 45 to more than 80 ft. Within the two investigation areas selected for subsurface evaluation, the thickest alluvial deposits encountered while drilling were in the west-central part of the Pella North investigation area and in the central part of the Pella East investigation area (figs. 4 and 5). As previously described, the total thickness of aquifer material in the Pella North and Pella East investigation areas was estimated as the thickness of geologic materials between the base of the overlying flood-plain silt, clay, and soil and the top of the underlying glacial drift. Therefore, the thickness of the aquifer material in the Pella North and Pella East areas is estimated to range from approximately 25 to more than 60 ft. Additional test drilling, using mud rotary or similar methods, would be needed to confirm the interpreted depth to and thickness of glacial drift, the altitude and nature of the underlying bedrock, and for more accurate determination of the particle size and mineral composition of the geologic materials composing the alluvial deposits in areas where borehole data are not available.

Figures 6 and 7 show the altitude of the glacial-drift surface in the Pella North and Pella East study areas. These maps were prepared from depth-to-glacial-drift data collected from USGS wells and test holes, and information extrapolated from 1:125,000-scale bedrock topographic maps by Hansen (1972, 1973, and 1985) and Cagle (1973). The greatest thicknesses of alluvial deposits, in excess of 60 ft, coincide with the areas of lowest altitude of the glacial-drift surface. The land-surface altitude of the South Skunk River flood plain is relatively uniform. Therefore, the deeper glacial-drift surface areas appear to be erosional channels in the glacial drift that have been subsequently filled by unconsolidated deposits. Geologic sections showing the general stratigraphy of the unconsolidated deposits in the Pella North and Pella East investigation areas are shown in figure 8.

Aquifer Properties

In-situ hydraulic-conductivity (slug) tests were performed in May 2001 in each observation well within the Pella North and Pella East investigation areas. Slug tests, used to estimate aquifer hydraulic characteristics, were performed using the technique described by Lohman (1972). After measuring the water level, each observation well was re-developed by pumping for approximately 30 minutes, at a discharge of 7.5 to 11 gal/min, to ensure that the water was relatively free of fine sediment. After pumping, the water level was allowed to return to static conditions before the slug test was performed.

During a slug test, water-level changes are measured in a well after displacing the initial water level by introducing or removing a cylinder (slug) of known displacement. Water-level changes following introduction or removal of the slug were measured with a pressure transducer and data recorder. Water levels were initially recorded at intervals of 0.03 seconds, but the recording interval was gradually increased as the slug-test duration increased. The hydraulic conductivity was calculated according to the Bouwer and Rice method for partially penetrating wells (Bouwer, 1989). Horizontal hydraulic-conductivity values ranged from about 24 ft/d in observation well PN–07 to 54 ft/d in observation well PN–04 (table 3).

Water Quality

Water samples were collected from the observation wells on July 12, 2001. Results were used to assess areal variations of constituent concentrations and to identify areas where selected constituents occur at concentrations that may be undesirable for drinking-water purposes. Specific conductance, pH, temperature, dissolved oxygen, bicarbonate, carbonate, and alkalinity were measured onsite at the time of sample collection. Laboratory analyses, performed at the USGS National Water-Quality Laboratory (NWQL) in Lakewood, Colorado, consisted of major ions (calcium, magnesium, sodium, potassium, sulfate, chloride, fluoride, bromide, and silica), trace metals (arsenic, iron, and manganese), and nutrients (nitrite nitrogen, nitrite plus nitrate nitrogen, ammonia nitrogen, and orthophosphorus). Concentrations of selected triazine pesticides and pesticide-degradation products (acetochlor, alachlor, ametryn, atrazine, bromacil, butachlor, butylate, carboxin, cyanazine, cycloate, deethylatrazine, deisopropylatrazine, diphenamid, hexazinone, metolachlor, metribuzin, prometon, prometryn, propachlor, propazine, simazine, simetryn, terbacil, terbuthylazine, trifluralin, and vernolate) as well

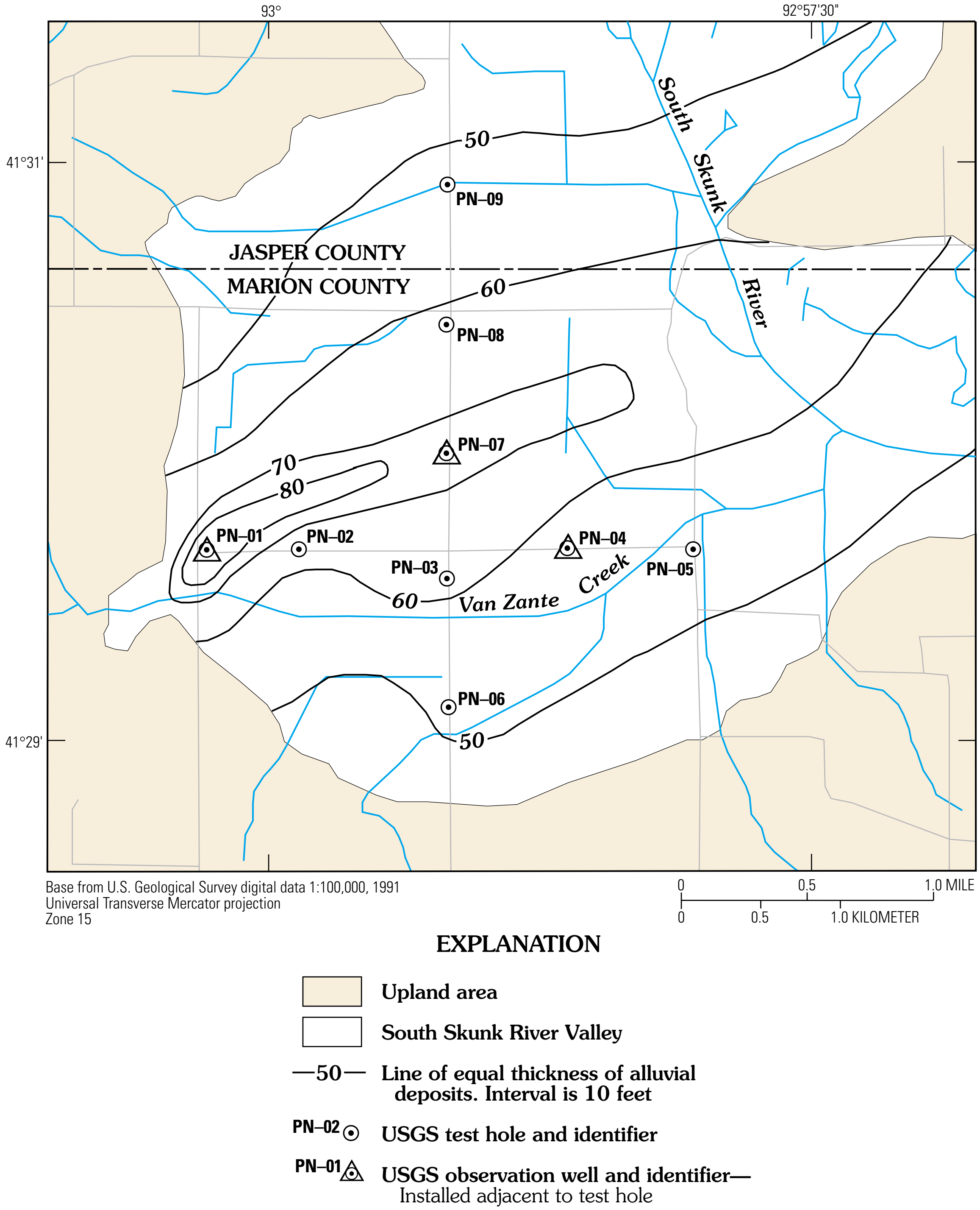


Figure 4. Interpreted thickness of alluvial deposits in Pella North investigation area near Pella, Iowa (based on test-hole and observation-well data).

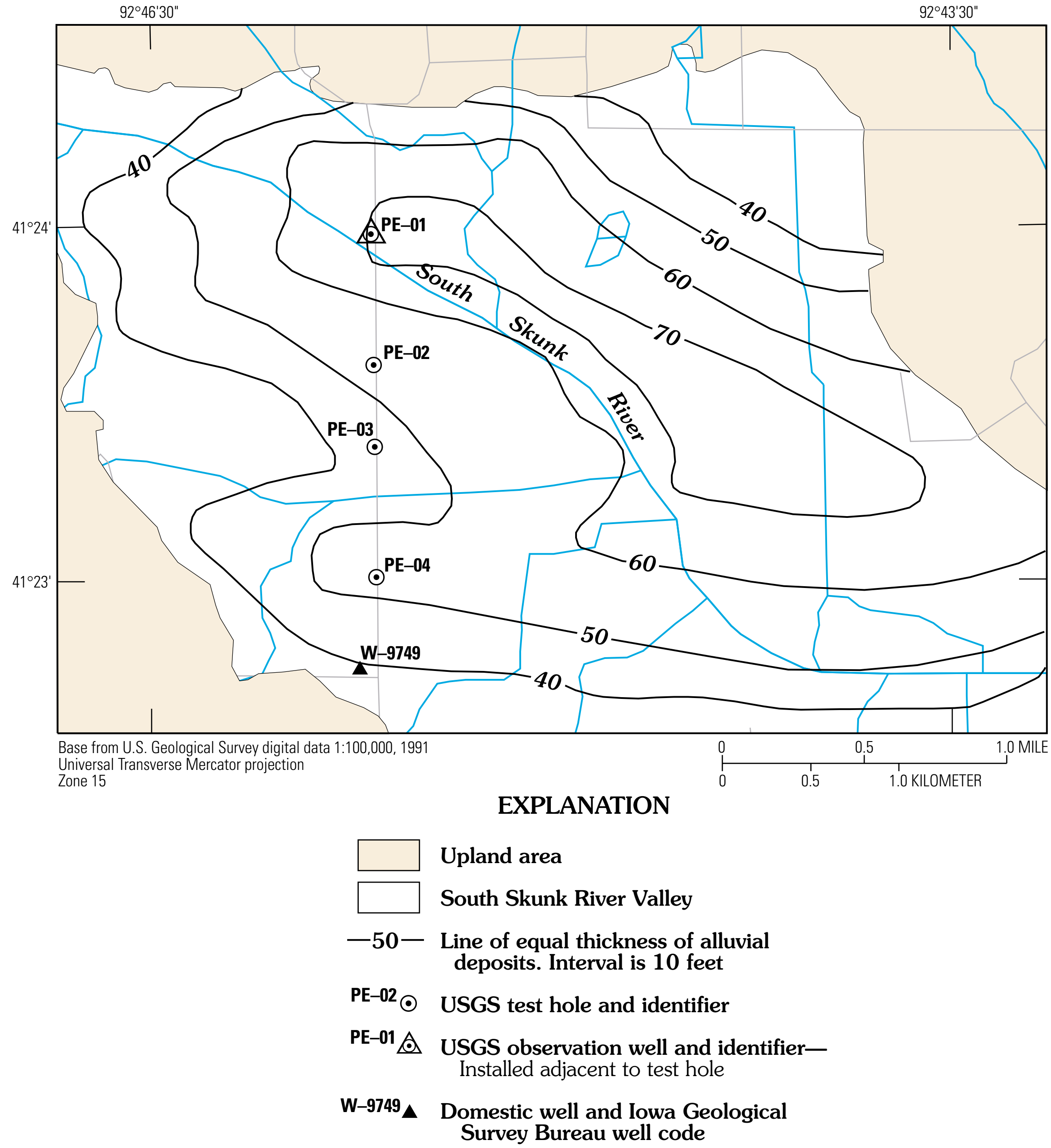


Figure 5. Interpreted thickness of alluvial deposits in Pella East investigation area near Pella, Iowa (based on test-hole and observation-well data).

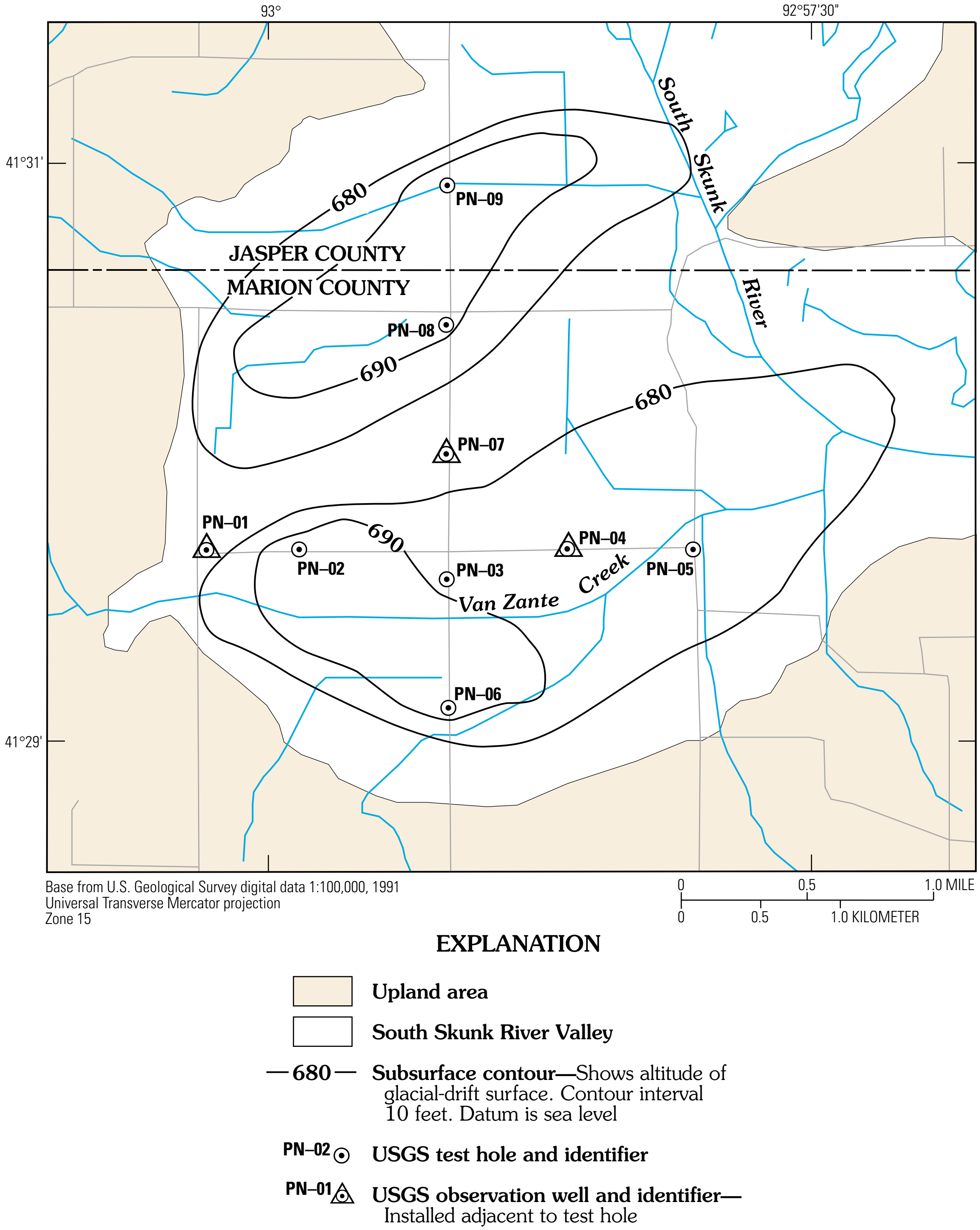
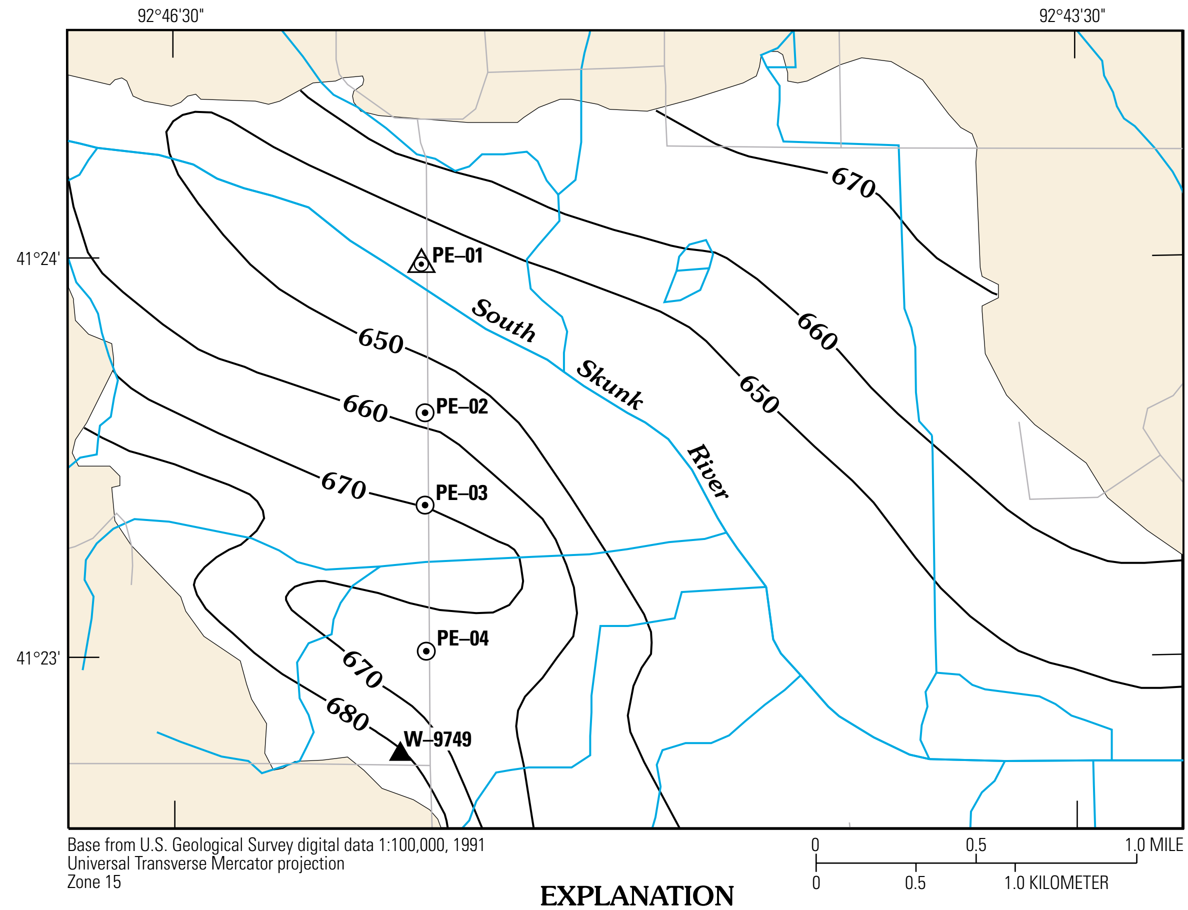


Figure 6. Altitude and configuration of glacial-drift surface in Pella North investigation area near Pella, Iowa (based on test-hole and observation-well data, and information extrapolated from Hansen, 1972, 1973, 1985; Cagle, 1973).



EXPLANATION

- **Upland area**
- **South Skunk River Valley**
- —650— **Subsurface contour**—Shows altitude of glacial-drift surface. Contour interval 10 feet. Datum is sea level
- PN–02 **USGS test hole and identifier**
- PN–01 **USGS observation well and identifier**—Installed adjacent to test hole
- W–9749 **Domestic well and Iowa Geological Survey Bureau well code**

Figure 7. Altitude and configuration of glacial-drift surface in Pella East investigation area near Pella, Iowa (based on test-hole and observation-well data, and information extrapolated from Hansen, 1972, 1973, 1985; Cagle, 1973).

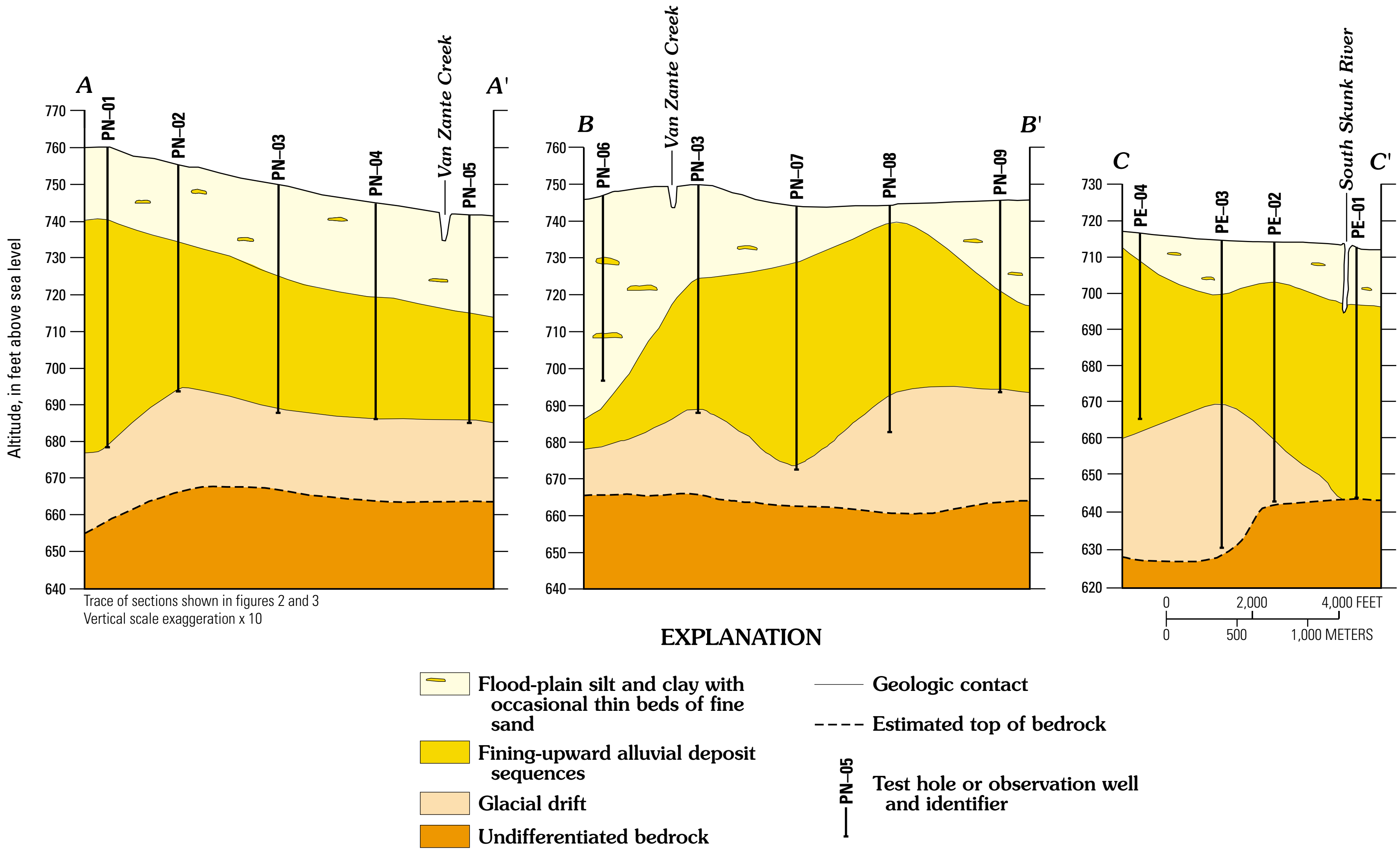


Figure 8. Geologic sections *A*–*A'* through *C*–*C'* based on test-hole data.

Table 3. Horizontal hydraulic-conductivity values estimated using slug tests for South Skunk River alluvial aquifer near Pella, Iowa, 2001

Observation wells (figs. 2 or 3)	Lithology near screened interval of well	Estimated horizontal hydraulic conductivity (feet per day)	
PN–01	Medium to coarse sand with gravel.	Slug in: Slug out:	46 53
PN–04	Medium to coarse sand with gravel.	Slug in: Slug in	54 49
PN–07	Medium to coarse sand with gravel; thin silt and clay lenses within aquifer interval.	Slug in Slug out:	33 24
PE–01	Medium to coarse sand with gravel.	Slug in: Slug out:	44 48

as dissolved organic carbon (DOC), and dissolved solids were measured by NWQL.

Physical properties and constituent concentrations for major ions, trace metals, nutrients, DOC, and dissolved solids detected in water samples collected from the investigation area test wells are summarized in table 4. Pesticides and pesticide-degradation products were not detected in any samples above the NWQL method detection limits and are not listed in table 4.

Samples from all test wells had relatively low concentrations of dissolved oxygen. Measured values of specific conductance, pH, temperature, alkalinity, bicarbonate, dissolved solids, and DOC were similar for all samples as were concentrations of calcium, magnesium, sodium, potassium, fluoride, bromide, silica, and manganese. Sulfate, chloride, orthophosphorus, arsenic, manganese, and iron concentrations varied. Sulfate was present in samples from all observation wells, ranging from 13 (observation well PN–04) to 80 mg/L (observation well PN–01). Chloride concentrations ranged from 4.0 (observation well PE–01) to 21 mg/L (observation well PN-01).

Concentrations of nutrients, except orthophosphorus, were similar in all ground-water samples. Ammonia nitrogen concentrations ranged from 0.47 (observation well PN–01) to 1.0 mg/L (observation well PN–07). Concentrations of nitrite nitrogen and nitrite plus nitrate were near or less than laboratory method detection limits (0.05 mg/L). Orthophosphorus concentrations ranged from less than 0.02 (observation wells PN–07 and PE–01) to 0.16 mg/L (observation well PN–04).

Arsenic concentrations ranged from less than 0.2 (observation well PN–04) to 8 μg/L (observation well PE–01). Iron concentrations ranged from 1,800 (observation well PN–01) to 16,000 μg/L (observation well PE–01). Manganese concentrations ranged from 220 (observation well PN–07) to 940 μg/L (observation well PE–01).

For reference, the quality of water in the South Skunk alluvial aquifer was compared to the regulations established by the U.S. Environmental Protection Agency (USEPA) Safe Drinking Water Act of 1986. The USEPA regulations established maximum levels for certain physical properties of, and chemical constituents in, finished (treated) drinking water. These regulations are Maximum Contaminant Levels (MCLs), Secondary Maximum Contaminant Levels (SMCLs), and Health Advisory Levels (HALs). These regulations apply to properties and constituents that may cause adverse human health effects if present in treated drinking water. MCLs are enforceable, health-based standards. SMCLs are established for properties or constituents that can affect the aesthetic quality of water (odor, appearance, taste) and may result in discontinued use of the water. HALs are nonregulatory levels that establish acceptable constituent concentrations for a specified period of exposure (1-day, 10-day, long term, and lifetime). Lifetime HALs are estimates of concentrations that would result in no known or anticipated adverse health effects (U.S. Environmental Protection Agency, 2002).

Raw water samples collected from all wells exceeded USEPA SMCL regulations for iron (SMCL = 300 μg/L) and manganese (SMCL = 50 μg/L). Arsenic was detected in a sample from observation well PE–01 at a concentration of 8 μg/L, which is slightly less than the arsenic MCL of 10 μg/L. No other physical properties or chemical constituents in samples from any of the wells exceeded USEPA regulations. Note that the referenced USEPA regulations are for treated, not raw, water samples (U.S. Environmental Protection Agency, 1996).

Municipal well fields for the cities of Newton and Oskaloosa (fig. 1) yield water from the South Skunk River alluvial aquifer north and south of Pella. A review of historical analytical results of ground-water samples from these well fields show that measured values of specific conductance, pH, temperature, dissolved oxygen, alkalinity, and dissolved solids were similar to results from observation wells in the Pella area. Concentrations of major ions, trace metals, and nutrients were very similar to the samples collected for this study.

Table 4. Selected water-quality characteristics and constituent concentrations in samples collected from observation wells in South Skunk River alluvial aquifer near Pella, Iowa, July 12, 2001

[µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; <, less than; E, estimated value]

Observation wells (figs. 2 or 3)	Site identification	Time (24-hour)	Specific conductance (µS/cm)	pH, water, whole, onsite, (standard units)	Temperature, water (°C)	Oxygen, dissolved (mg/L)	Bicarbonate, onsite (mg/L as HCO_3)	Carbonate, onsite (mg/L as CO_3)	Alkalinity, onsite (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L)
PN–01	412940093001701	1300	576	7.4	14.3	1.0	220	0	180	69
PN–04	412941092583801	1605	622	7.3	13.4	.6	380	0	320	84
PN–07	413006092591001	1435	672	7.2	13.2	.8	380	0	310	85
PE–01	412359092454101	1030	603	6.9	14.5	1.0	360	0	300	88

Observation wells (figs. 2 or 3)	Magnesium, dissolved (mg/L)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Bromide, dissolved (mg/L as Br)	Silica, dissolved (mg/L as SiO_2)	Arsenic, dissolved (µg/L as As)	Iron, dissolved (µg/L as Fe)
PN–01	26	11	0.9	80	21	0.3	0.12	30	1	1,800
PN–04	25	15	1.4	13	4.8	.3	.16	30	<.2	5,280
PN–07	30	13	1.6	42	5.9	.4	.11	30	.4	5,000
PE–01	24	5.6	1.8	35	4.0	E.1	.09	34	8	16,000

Observation wells (figs. 2 or 3)	Manganese, dissolved (µg/L as Mn)	Nitrogen, nitrite (mg/L as N)	Nitrogen, nitrite plus nitrate, dissolved (mg/L as N)	Nitrogen, ammonia, dissolved (mg/L as N)	Orthophosphorus, dissolved (mg/L as P)	Carbon, organic, dissolved (mg/L as C)	Solids, residue at 180°C, dissolved (mg/L)
PN–01	420	E0.003	E0.04	0.47	0.05	2.8	384
PN–04	240	E.004	<.05	.97	.16	2.5	369
PN–07	220	<.006	<.05	1.0	<.02	8.2	411
PE–01	940	.006	<.05	.65	<.02	3.0	406

SUMMARY

The city of Pella currently obtains its municipal water supply from the alluvial aquifer adjacent to the Des Moines River and a Cambrian-Ordovician (Jordan) aquifer well. Yields from the alluvial wells are affected by the river stage, which is controlled by discharge from Lake Red Rock. Additional sources of water in the vicinity of Pella are needed to meet projected increased water needs.

To help address concerns about future sources of water supply, the U.S. Geological Survey, in cooperation with city of Pella, conducted a study from 2000–01 to provide information about the sources of ground water (unconsolidated and bedrock aquifers) in selected parts of Jasper, Mahaska, and Marion Counties, within a 10-mi radius of the city of Pella. The study focused on supplementing available information for the alluvial deposits along the South Skunk River Valley north and east of Pella.

Available hydrologic and geologic information was compiled from the scientific literature and previous studies in the Pella area. Additional thickness and lithology data for the alluvial deposits in the South Skunk River Valley were collected for this study at selected sites from October 2000 through March 2001. Water-quality samples were collected in July 2001 from four observation wells installed in the South Skunk River alluvial aquifer near Pella.

Test-hole and observation-well drilling were used to collect geologic information for the unconsolidated material in the South Skunk River Valley. Test holes were drilled to determine the thickness and lithology of the alluvial deposits and to construct observation wells for measuring water levels, determining hydraulic characteristics, and collecting water-quality samples.

The alluvial deposits along the South Skunk River Valley near Pella consist of sand, gravel, silt, and clay deposits of glacial and fluvial origin. The sand and gravel are commonly interbedded with silt and clay lenses in the upper 20 ft of the deposits. Deeper materials appear to be primarily sand and gravel. Within the Pella North and Pella East investigation areas, the alluvial aquifer is underlain by clay-rich glacial drift. Thicknesses of the alluvial deposits (flood-plain clay and silt plus alluvial aquifer) in the South Skunk River alluvial valley in the study area range from about 60 to more than 80 ft. Thickness of the alluvial aquifer materials in the study area range from about 25 to 60 ft.

Water quality in the South Skunk River alluvial aquifer was similar among the samples collected from four observation wells in the investigation areas. Samples from all observation wells had relatively low concentrations of dissolved oxygen. Measured values of specific conductance, pH, temperature, alkalinity, bicarbonate, dissolved solids, and dissolved organic carbon were similar for all samples as were concentrations of calcium, magnesium, sodium, potassium, fluoride, bromide, and silica. Sulfate was present in water from all sampled wells, ranging from 13 to 80 mg/L. Chloride concentrations ranged from 4.0 to 21 mg/L. Concentrations of nutrients, except orthophosphorus, were similar in all ground-water samples. Ammonia nitrogen concentrations ranged from 0.47 mg/L to 1.0 mg/L. Concentrations of nitrite nitrogen and nitrite plus nitrate were near or less than laboratory method detection limits (0.05 mg/L). Orthophosphorus concentrations ranged from less than 0.02 to 0.16 mg/L. Iron concentrations ranged from 1,800 to 16,000 μg/L; the U.S. Environmental Protection Agency (USEPA) has established a Secondary Maximum Contaminant Level (SMCL) of 300 μg/L for iron. Manganese concentrations ranged from 220 to 940 μg/L (SMCL = 50 μg/L). Arsenic concentrations ranged from less than 0.2 to 8 μg/L which is slightly less than USEPA's Maximum Contaminant Level (MCL) of 10 μg/L.

The chemical quality of water from observation wells installed in the South Skunk River alluvial aquifer near Pella is similar to water from municipal wells installed in the South Skunk River alluvium at Newton and Oskaloosa, located north and south of Pella, respectively. Analyses of ground-water samples from these well fields show that concentrations of major ions, nutrients, and trace metals were very similar to the water samples collected for this study. Measured values of specific conductance, pH, temperature, dissolved oxygen, alkalinity, and dissolved solids also were similar.

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