A SUMMARY OF THE GROUND-WATER RESOURCES AND GEOHYDROLOGY OF GRAND COUNTY, UTAH

by

Chris Eisinger and Mike Lowe

Utah Geological Survey

CIRCULAR 99 **MAY 1999**

UTAH GEOLOGICAL SURVEY

a division of

Utah Department of Natural Resources

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Cover photograph is the mouth of the Dirty Devil River at Lake Powell.
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TABLE OF CONTENTS

FIGURES

TABLES

A SUMMARY OF THE GROUND-WATER RESOURCES AND GEOHYDROLOGY OF GRAND COUNTY

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ABSTRACT

In Grand County, ground water has been withdrawn primarily from two types of aquifers: fractured rock and unconsolidated deposits. Some of the better water-yielding rock units are grouped together into nine aquifers, including: the Lower Paleozoic aquifer, the Cutler aquifer, the Wingate aquifer, the Navajo aquifer, the Entrada aquifer, the Morrison aquifer, the Dakota aquifer, the Wasatch aquifer, and the Parachute Creek aquifer.

The Navajo Sandstone is one of the shallowest and most permeable formations, generally producing water having low total-dissolved-solids concentrations; it is therefore the target for most bedrock wells and the principal source of drinking water in southern Grand County. Unconsolidated aquifers are also an important source of ground water, especially in the Spanish and Castle Valley areas.

Recharge to Grand County aquifers is principally from infiltration of precipitation and stream flow, primarily originating in the La Sal Mountains and Book Cliffs. Sources of discharge in Grand County include: outflow to the Colorado and Green Rivers; evapotranspiration by phreatophytes and hydrophytes; spring flow and seeps; consumptive use of ground water for irrigation, public supply, domestic purposes, and sewage treatment; and subsurface outflow.

INTRODUCTION

This report summarizes published information regarding ground-water conditions in Grand County. During the preparation of this report we identified several types of information that are not presently available, but can be useful for evaluating ground-water resources, including: (1) structure contour maps showing the depth to aquifers, (2) isopach maps showing the thickness of aquifers, and (3) fracture domain maps showing the predominant orientations of rock discontinuities.

SETTING

Grand County (figure 1), a rural county with a 1990 Census population of 6,620, is in southeastern Utah in the Colorado Plateau physiographic province (Stokes, 1977). Typical of areas in the Colorado Plateau, Grand County's landscape is characterized by high plateaus, deeply incised canyons, and long, continuous cliff faces. Other major landforms include the La Sal Mountains and several collapsed salt anticline valleys, such as Spanish Valley and Castle Valley.

Average annual precipitation in the county ranges from greater than 30 inches in the La Sal Mountains to about 6 inches along the Green River near the city of Green River (Blanchard, 1990).

Three major, perennial streams flow within or along the border of Grand County: these include the Colorado River and two of its tributaries, the Dolores River and the Green River. Mill and Pack Creeks near Moab, and Cottonwood Wash near I-70, are also perennial streams (Blanchard, 1990), but parts of the Pack Creek channel are dry except during periods of heavy runoff because flow is diverted for irrigation (Sumsion, 1971). Most of the other streams in the county are intermittent, at least in their lower reaches; therefore, ground-water aquifers are a major source of culinary water.

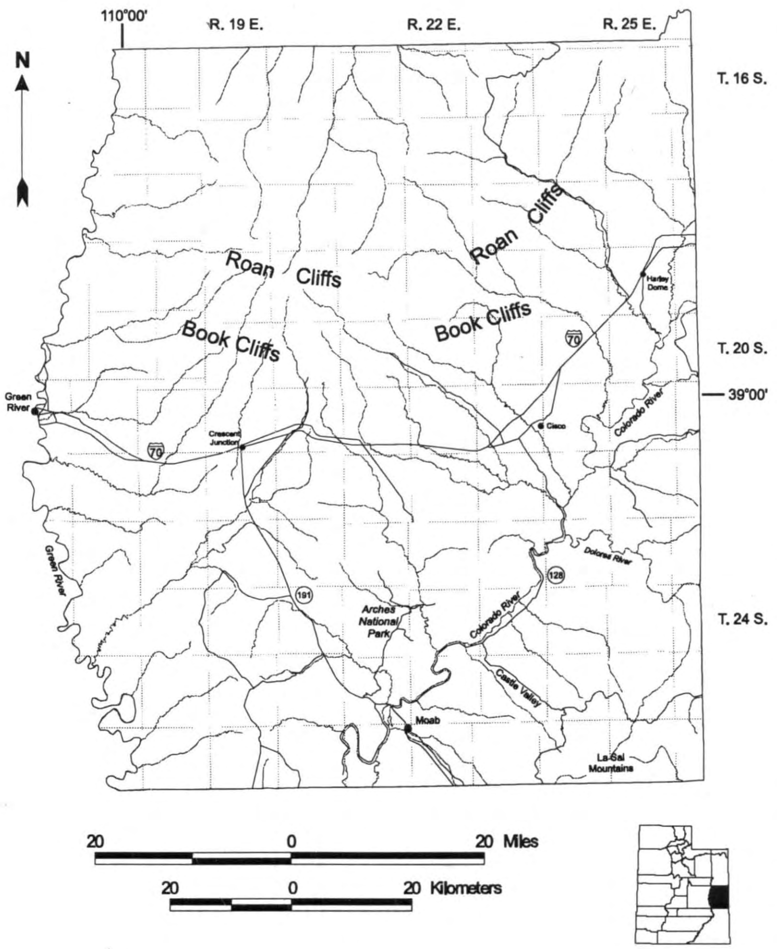

Figure 1. Grand County, Utah location map.

CHARACTERISTICS OF MAJOR AQUIFERS

In Grand County, ground water has been withdrawn during this century primarily from two types of aquifers: fractured rock and unconsolidated deposits. The characteristics of geologic units in Grand County, along with their hydrologic properties and significance, are presented in table 1. The principal aquifers are discussed below.

Fractured-Rock Aquifers

All of the bedrock units in Grand County can be water bearing to some degree, depending on permeability, thickness, and location with respect to recharge areas. The permeability of bedrock aquifers depends both on primary permeability due to interconnected void spaces between particles, and secondary permeability due to fractures (faults and joints). Primary permeability is important in some rock units, such as the Navajo Sandstone, but the amount of secondary permeability is the primary factor determining the ability of most bedrock aquifers to yield water in Grand County.

The major water-yielding rock units in Grand County are part of either an upper or lower hydrologic system (Rush and others, 1982; Weir, Maxfield, and Hart, 1983; Weir, Maxfield, and Zimmerman, 1983; Blanchard, 1990). The two systems are separated by impermeable salt beds of the Pennsylvanian Paradox Formation, which underlie much of the county. The lower hydrologic system includes all units below the base of the salt-bearing beds (table 1). The upper hydrologic system contains all consolidated and unconsolidated units above the Paradox Formation (table 1). The Paradox Formation acts as a confining bed that provides an upward ground-water gradient for the lower system in the Grand County area, but also typically prevents upward leakage from the lower system to the upper system (Rush and others, 1982; Weir, Maxfield, and Hart, 1983).

Some of the better water-yielding rock units are grouped together into nine aquifers, one in the lower hydrologic system and eight in the upper hydrologic system (table 1). From oldest to youngest (in order of decreasing depth at any given location), these aquifers are the Lower Paleozoic aquifer, the Cutler aquifer, the Wingate aquifer, the Navajo aquifer, the Entrada aquifer, the Morrison aquifer, the Dakota aquifer, the Wasatch aquifer, and the Parachute Creek aquifer (table 1). The aquifers are not laterally or vertically homogenous and they are treated individually in the following discussion, since little is known about interaction between the

Table 1. Characteristics of the major geologic units and their hydrologic characteristics and significance, Grand County (adapted from tables by Sumsion, 1971; Schlotthauer and others, 1981; Blanchard, 1990; Gloyn and others, 1995; and Gwynn, 1995; stratigraphic thicknesses after Hintze, 1988).

Era	System	Geologic Unit	Thickness (ft)	Description	Hydrologic characteristics and significance	Aquifer System
Cenozoic	Quaternary	Valley-fill deposits	0 - 100 in Green River & Cisco areas 0 - 300 in Moab/La Sal area	Unconsolidated deposits of alluvial sand and gravels, colluvial debris including landslide and pediment deposits, glacial till, eolian sands, and terrace deposits. Generally rounded to subrounded gravel, cobbles, and boulders in a clean sandy matrix. In many cases deposits are reworked into well-sorted and well-stratified floodplain deposits with sand and gravel channel deposits.	Principal aquifer, low to high permeability; yields small to large quantities of water to wells and springs. Highest discharge in the Moab well field area of Spanish Valley.	Unconsolidated Aquifers (plate 8)
	Tertiary	Intrusive igneous rocks of the La Sal Mountains		Consists of diorite, monzonite, and syenite porphyry that intruded older sedimentary formations as dikes, sills, stocks, and laccoliths.	Very low permeability. Known to yield water only where jointed, fractured, or faulted. Recharges adjacent permeable sedimentary rocks. Yields fresh water.	
		Green River Formation Parachute Creek Member	0 - 5,000+ in northern Grand County	Present only in the northern part of county. Interfingering lacustrine claystone, sandstone, and carbonate beds Chiefly marlstone and oil shale, with some sandstone, siltstone, and tuff.	Yields fresh water to springs, from less than 1 gpm to about 20 gpm.	Parachute Creek Aquifer (plate 7)
		Wasatch Formation	1,000 - 1,600	Continental deposits, ranging from coarse conglomerate to fine sandstone with shale and mudstone.	Yields fresh water to one spring, about 30 gpm.	Wasatch Aquifer (plate 7)
Mesozoic	Cretaceous	Mesaverde Group	1,150 - 2,500 in Cisco area 1,520 - 1,950 in Green River	Sandstones and mudstones interbedded with shale and coal beds. Castlegate Sandstone is a cliff-forming deltaic sandstone.	Yields some water. Sandstone units are potential aquifers.	Confining Unit
		Mancos Shale	3,360 - 4,000+ in northern Grand County 300 - 1100 in Moab/La Sal area	Marine shale that contains a few thin beds of sandstone or limestone, and is gradational with and laterally interfingers with the overlying Mesaverde Group. The Mancos Shale has three members: The Blue Gate Member at the top, a shale that contains thin beds of bentonite or shaly sandstone and limestone; the Ferron Sandstone Member in the middle, a fine-grained, thin-bedded sandstone and sandy shale; and the Tununk Member at the base, a mudstone and shale that contains some thin bentonite beds.	Very low permeability; a barrier to the movement of water unless fractured. Water in the Mancos Shale, or in alluvium or colluvium derived from it, is saline. The Ferron Sandstone Member yields some water to springs.	Confining Unit

Era	System	Geologic Unit	Thickness (ft)	Description	Hydrologic characteristics and significance	Aquifer System
Mesozoic	Cretaceous	Dakota Sandstone, Cedar Mountain Formation, & Burro Canyon Formation	0 - 240 in northern Grand County 80 - 450 in La Sal area	Shale with fluvial sandstones. Mostly eroded in southern third of county.	Generally very low to low permeability except where faulted or fractured. Yields water to a few small springs.	Dakota Aquifer (plate 6)
	Jurassic	Morrison Formation	400 - 900	Continental deposits of mostly fluvial shale, siltstone, mudstone, and sandstone that contain a few beds of fresh water limestone.		
		Brushy Basin Member		Laminated, bentonitic mudstone and siltstone containing a few lenses of chert-pebble conglomerate and sandstone; usually variegated red, green, and purple color.	The Brushy Basin Member has very low permeability and is usually a barrier to water movement except where faulted or fractured. Known to yield slightly saline water, less than 1 gpm, to one well.	Confining Unit
		Salt Wash Member		Fine- to medium-grained, sometimes-conglomeratic sandstone interbedded with mudstone; contains thin beds of calcareous and gypsiferous shale and has thin beds of limestone near the base of the member.	Slightly permeable; yields small quantities of water to seeps and springs northwest of Moab. Yields saline water to one spring on South Mesa.	Morrison Aquifer (plate 5)
		Tidwell Member		Fine- to medium-grained siltstone and sandstone; thin to medium bedding; gray limestone in thin beds and locally contains large white siliceous concretions.	Moderately permeable; yields water to springs; a potential aquifer.	
		Summerville-Curtis Formation	100 - 400 in Green River area	Shale and siltstone of marginal-marine, tidal flat, and fluvial facies; calcareous and gypsiferous, laminated shale, siltstone, and very fine to fine-grained sandstone; contains an irregular zone of chert (and, locally, limestone) concretions near its top. Eroded in eastern part of county a Jurassic unconformity.	Very low to low permeability; a barrier to the movement of water except where faulted or fractured; a confining layer.	Confining Unit
		Entrada Sandstone	290 - 920 in the Moab/La Sal area	Sandstones of shoreface, shallow-marine, coastal-dune, and continental-eolian facies.		Entrada Aquifer (plate 4)
		Moab Member		Medium-grained, well-sorted, massive, cross-bedded sandstone believed to have been a coastal-dune complex.	Primarily a recharge unit, especially where fractured.	
		Slick Rock Member	190 - 470 in the Green River and Cisco areas	Very fine- to medium-grained, massive, cross-bedded sandstone of eolian and possibly shallow-marine origin.	Principal water-yielding sandstone of the Entrada. Yields fresh water to seeps and springs, generally less than 5 gpm.	
		Dewey Bridge Member		Poorly bedded, sandy siltstone, and silty sandstone deposited in a shallow-marine environment.	Confining unit. Low transmissivity and conductivity values.	

Era	System	Geologic Unit	Thickness (ft)	Description	Hydrologic characteristics and significance	Aquifer System
Mesozoic	Jurassic	Carmel Formation	220 - 300 in the Green River area	Marine gypsum, limestone, shale, and calcareous sandstone. Crops out south of the City of Green River; pinches out towards eastern part of county.	Not known to yield water.	Confining Unit
		Navajo Sandstone	0 - 550	Well-rounded, well-sorted, massive, fine- to medium-grained eolian sandstone. Locally contains beds of cherty, dolomitic, freshwater limestone that were likely deposited in playa lakes. Limestone horizons near top of formation.	Low primary permeability, but where fractured yields small to large quantities of water. Yields freshwater to seeps, springs, and wells throughout the area. Spring discharge ranges from less than 5 to more than 300 gpm. Well discharge is as much as 2,000 gpm.	Navajo Aquifer (plate 3)
		Kayenta Formation	0 - 250 in northern Grand County 140 - 300 in the Moab/La Sal area	Very fine- to coarse-grained, irregularly bedded, locally conglomeratic, fluvial sandstone, siltstone, and shale, with beds of mudstone or lacustrine limestone.	Very low to low permeability; somewhat of a barrier to the movement of water except where faulted or fractured. In areas where Navajo and Kayenta are flat lying, springs issue from base of Navajo at contact with the Kayenta. Unit is more permeable in the Mill Creek-Spanish Valley area and, along with the Navajo and Wingate Sandstones, forms the Glen Canyon aquifer.	
		Wingate Sandstone	300 - 400 in the Green River and Cisco areas 150 - 450 in the Moab/La Sal area	Well-sorted, very fine- to medium-grained, calcareous, massively bedded, well-cemented, eolian sandstone. Forms vertical cliffs in most exposures. Found intermittently in the southern half of Grand County.	Very low to low permeability except where faulted or fractured. Water from the Wingate is fresh to moderately saline, but locally may be very saline to briny. Yields freshwater to seeps and springs in the Moab Valley-Colorado River area. Recharge is dependent upon the permeability and competency of overlying Kayenta.	Wingate Aquifer (plate 3)
	Triassic	Chinle Formation	90 - 540 in northern Grand County 150 - 650 in the Moab/La Sal area	Siltstone and conglomeratic sandstone near the top; flood-plain, lacustrine, bentonitic mudstone and marly mudstone in the middle, and fluvial, conglomeratic sandstone and mudstone in the lower part. Crops out in the south and southeastern parts of Grand County.	Very low to low permeability; a barrier to the movement of water except where jointed, faulted, or fractured. Yields little water in Grand County.	Confining Unit
Mesozoic	Triassic	Moenkopi Formation	670 - 910 in the Green River area 590 - 750 in the Moab/La Sal area	Upper unit: shaly siltstone, thin, flaggy sandstone, and thick massive sandstone that, in places, contains a thin marine limestone bed. Lower unit: interbedded thin, commonly contorted, beds of fine- to medium-grained, micaceous, silty sandstone and shaly siltstone that locally contain gypsum beds. Represents a marginal marine deposit that grades from tidal-flat, deltaic, and fluvial beds in the eastern part of the county to a shallow-water, marine limestone facies in the western part of the county. Unit is present everywhere in county, but crops out only in the south and southeast parts.	Commonly very low permeability; a barrier to the movement of water except where jointed, faulted, or fractured.	Confining Beds

Era	System	Geologic Unit	Thickness (ft)	Description	Hydrologic characteristics and significance	Aquifer System
Paleozoic	Permian	Cutler Group	400 - 6,000 + in the Moab/La Sal area	Fluvial arkose and arkosic fanglomerates; conglomerates; and finer-grained continental and nearshore marine clastics. Underlies all of the county except where removed by erosion on the crests of the salt anticlines and in the deeper canyons.	Very low to low permeability except where faulted or fractured. Shaly beds are barriers to water movement except where faulted or fractured.	Cutler Aquifer (plate 2)
		White Rim	0 - 5,000 in the Cisco area	A medium- to coarse-grained, well-sorted sandstone that is the nearshore and sandbar-complex facies.	Yields slightly saline water to wells in Taylor Canyon; yields freshwater to seeps along margin of outcrop.	
		Cedar Mesa Sandstone	1,300 - 2,000 in the Green River area	Fine- to coarse-grained, thickly cross-bedded, eolian sandstone that has been deposited in a shallow-marine foreshore environment.	May be an aquifer, but not known to yield water in the Grand County area.	
		Elephant Canyon Formation	0 - 1,500 in the Moab/La Sal area 1,000 - 1,200 in the Green River area	Marine carbonate deposits, associated nearshore and shoreline deposits, and coastal-plain fluvial deposits of fine- to medium-grained, calcareous sandstone; partly gypsiferous, micaceous siltstone and sandy shale; and thin- to thick-bedded, cherty limestone. This formation underlies the entire county except where eroded on the crests of salt anticlines and in the deeper canyons. To east Cedar Mesa Sandstone and Elephant Canyon Formation interfinger with undifferentiated Cutler - a thick sequence of medium to coarse grained arkosic sandstone and conglomerate.	Sandstones are permeable, but the formation generally has a low intrinsic hydraulic conductivity. Water from the Elephant Canyon Formation is moderately saline to briny.	
Paleozoic	Pennsylvanian	Hermosa Group	3,500 - 7,000+ in the Moab/La Sal area 0 - 7,000 in northern Grand County	Hermosa Group has been divided into three formations. The Honaker Trail and Pinkerton Trail Formations include thin- to thick-bedded limestone and dolomite that contains beds of fine-grained micaceous sandstone and siltstone, sandy shale, and occasional thin interbeds of shale and anhydrite. Reefs and algal bioherms are also common. The Paradox Formation contains a thick sequence of evaporite deposits interbedded with shale, carbonate, and fine-grained sandstone and siltstone in what was the deepest part of the Paradox Basin, and limestone and dolomite interbedded with shale and fine-grained sandstone to the west and south of the evaporite sequence. The depositional environments range from marine shoal and shelf to hypersaline evaporite basin. Toward the Uncompahgre Plateau, all three members interfinger with coarse arkosic sediments. The Hermosa Group is thickest in the salt anticlines in the northeastern part of the county.	Very low to high permeability. Evaporites are a barrier to the movement of water. Carbonate rocks, except reefs and bioherms, usually are barriers to the movement of water except where faulted or fractured or where solution channels have developed. Reef and biohermal deposits may be highly permeable and can have porosities of as much as 30 percent. Except at outcrops, water from the Hermosa Group usually is moderately saline to briny. Dissolved-solids concentrations can exceed 400,000 mg/L.	Confining Beds
		Molas Formation	0 - 100	Siltstone, silty shale, and calcareous sandstone that contains some thin-bedded limestone; locally conglomeratic, particularly near the base. A continental deposit commonly identified as regolith that developed on a karst surface.	Very low to low permeability; probably a barrier to the movement of water except where faulted or fractured.	Confining Beds

Era	System	Geologic Unit	Thickness (ft)	Description	Hydrologic characteristics and significance	Aquifer System
	Mississippian	Leadville Limestone	600 - 800 in the Green River area 300 - 600 in the Moab/La Sal area	Upper part: dense, thin-bedded, sometimes oolitic, limestone. Lower part: massive, cherty dolomite that locally contains thin beds of limestone near the top and also may contain thin beds of shale. In other areas this formation is called the Redwall Limestone. Deposited on a broad, relatively flat, shallow-water, marine shelf.	Very low to low permeability except where faulted or fractured, or where solution channels have developed. Water from the Leadville Limestone is generally moderately saline to briny.	Confining Beds
Paleozoic	Devonian	Ouray Limestone	0 - 150	Dense, commonly oolitic limestone that locally contains partings of shale. Deposited in a quiet-water, shallow marine environment.	Very low to low permeability except where faulted or fractured. Water is moderately saline to briny.	Lower Paleozoic Aquifer (plate 1)
		Elbert Formation	125 - 300	Thin-bedded, sandy dolomite that contains sandy shale. McCraken Sandstone Member is a fine- to medium-grained, poorly sorted, tightly cemented sandstone, commonly glauconitic, with streaks of sandy dolomite. Deposited in a shallow-water, in part intertidal, marine-shelf environment.	Low permeability except where faulted or fractured. Like the Ouray Limestone, water is moderately saline to briny.	
	Cambrian	Lynch Dolomite	800 - 1,000	Massive marine dolomite and interbedded shale.	Probably very low permeability except where faulted or fractured. Water is very saline to briny.	Confining Beds
		Bright Angle Shale	0 - 100 in the Moab/La Sal area	Shale interbedded with fine-grained sandstone, siltstone, dolomite, and limestone. The formation grades from carbonate to shale to siltstone and sandstone from west to east.	Probably very low permeability; a barrier to the movement of water except where faulted or fractured.	
		Ignacio Quartzite	100 - 300 in the Moab/La Sal area	A basal transgressive marine deposit of thin-bedded, slightly friable sandstone.	Very low permeability except where fractured or faulted.	
Precambrian				Undifferentiated igneous and metamorphic rocks; crystalline rocks; found in the eastern part of Grand County near Colorado River.	Very low permeability; a barrier to the movement of water except where jointed, faulted, or fractured.	

aquifers or the degree to which they are isolated or perched due to confining beds. In general, the shallowest aquifers are best because they commonly contain higher quality water than deeper aquifers and are more easily accessible. Ground water for consumptive use comes almost exclusively from the upper hydrologic system.

Ground-water information is not equally available for all areas or all geologic units in Grand County. Other potential aquifers may be identified as a result of future development and/or further investigation.

Lower Paleozoic Aquifer

The aquifer in the lower hydrologic system, the Lower Paleozoic aquifer, consists of, from oldest to youngest, the Devonian Elbert Formation (especially the McCracken Sandstone Member or its equivalent), the Devonian Ouray Limestone, and the Mississippian Leadville Limestone (also called the Leadville Dolomite or Redwall Limestone in some areas) (Rush and others, 1982). These geologic units do not crop out in Grand County, but likely underlie most of the county (plate 1) except where intruded by Tertiary intrusive rocks. This aquifer is an important source of ground water in some areas of San Juan County where it is called the Redwall aquifer (Gloyn and others, 1995; Lowe, 1996). Based on drill-stem tests, Weir, Maxfield, and Hart (1983) rated the Lower Paleozoic aquifer as having the highest average hydraulic conductivity of all the units they evaluated. However, the Lower Paleozoic aquifer is generally too deep (generally greater than 3,900 feet, based on Rush and others [1982, table 15]) in most areas of Grand County to be an economically feasible target for water wells.

Cutler Aquifer

Regionally, the Permian Cutler Formation (plate 2) is part of a confining unit (Rush and others, 1982; Weir, Maxfield, and Hart, 1983), but permeable portions of the formation are a locally important aquifer. The Cutler Formation consists of subarkosic to arkosic sandstone, conglomeratic sandstone, and conglomerate interbedded with mudstone and siltstone which in outcrop forms ledgy slopes interrupted by short cliffs (Ross, in press). The Cutler Formation ranges in thickness from 0 to 5,000 feet in east-central Grand County (Ross, in press). Potential aquifers include the Cedar Mesa Sandstone Member, the White Rim Sandstone Member, and permeable portions of the undifferentiated Cutler Formation (table 1). The Cedar Mesa Sandstone is an important aquifer in San Juan County (Gloyn and others, 1995; Lowe, 1996), but is not known to yield water to wells or springs in Grand County.

The White Rim Sandstone crops out in Canyonlands National Park near the mouth of the Green River and has many springs and seeps along its lower contact. While none of these springs and seeps individually discharge more than a gallon per minute, three wells drilled into the White Rim Sandstone yield from 25 to 100 gallons per minute (Huntoon, 1977). Huntoon (1977) notes that, "...parts of the White Rim Sandstone that lie below 4,200 feet in elevation are generally saturated and the water occurs under artesian conditions."

The undifferentiated Cutler Formation near Castle Valley is a source of water for about 30 wells (Blanchard, 1990). Well depths generally range from 150 to 300 feet below the land surface (Snyder, 1996a,b). Five wells in this area have discharge rates ranging from 20 to 40 gallons per minute (Blanchard, 1990).

Wingate Aquifer

The Wingate Sandstone, which comprises the Wingate aquifer (plate 3), crops out in the southern half of Grand County, typically forming an abrupt, high, desert-varnished cliff. The Wingate Sandstone is the lowest formation of the Jurassic Glen Canyon Group (Hintze, 1988). The Wingate Sandstone is fine grained and well sorted, with massive, tabular cross-stratification (Sumsion, 1971). It is typically between 150 and 450 feet thick in the Moab-Arches-La Sal area

(Hintze, 1988), and generally capped by the erosion-resistant Kayenta Formation.

The amount of water that infiltrates into the Wingate Sandstone is directly related to the permeability and amount of fracturing in the overlying Kayenta Formation (Blanchard, 1990). Where the Kayenta is impermeable or highly competent, negligible recharge to the Wingate aquifer occurs. Conversely, where the Kayenta is highly fractured, the Wingate is readily infiltrated and recharged. Although the Kayenta Formation is a confining layer that in most areas of Grand County separates the Wingate aquifer from the overlying Navajo aquifer, in the Mill Creek-Spanish Valley area the Kayenta consists mostly of sandstone and the three units form a single aquifer called the Glen Canyon aquifer (Blanchard, 1990; Steiger and Susong, 1997).

The Wingate aquifer's intrinsic permeability is low because of its fine-grained nature, but it is a competent formation that can yield moderate quantities of water where intensely fractured (Sumsion, 1971). Spring discharge for the Wingate ranges from 10 to 240 gallons per minute (Blanchard, 1990). Estimated hydraulic conductivity ranges from 0.1 feet/day to 0.4 feet/day, while the Wingate aquifer's transmissivity ranges between 40 and 150 square feet/day (Jobin, 1962, in Blanchard, 1990).

Navajo Aquifer

The Navajo Sandstone is the uppermost formation of the Jurassic Glen Canyon Group (Hintze, 1988). It is fine grained, displays thick, eolian (wind formed) cross-beds, is weakly cemented by silica or calcium carbonate, and crops out extensively in southern Grand County as massive cliffs and domes alternating with small depressions (Sumsion, 1971). The Navajo also contains thin, lenticular beds of gray, sandy limestone (Sumsion, 1971). The unit is between 0 and 550 feet thick in the Moab-Arches-La Sal area (Hintze, 1988).

The Navajo aquifer yields water to seeps and springs throughout its outcrop area. The Navajo Sandstone is the shallowest and most permeable formation in the Glen Canyon Group (Feltis, 1966), and is therefore the target for most bedrock wells drilled in southern Grand County. The Glen Canyon Group is the principal source of drinking water in the Moab and Spanish Valleys area of southern Grand County (Steiger and Susong, 1997). Plate 3 shows the general area where the Glen Canyon Group is present in Grand County, and where the total thickness of overlying rock is greater than 2,000 feet (Freethey and Cordy, 1991). Spring discharge from the Navajo ranges from less than 5 gallons per minute to more than 300 gallons per minute, and well discharge is as high as 2,000 gallons per minute (Blanchard, 1990).

The Navajo aquifer has the greatest transmissivity values of the major sandstone units in the Colorado Plateau area because it is thick, well sorted, and has a relatively high permeability (Jobin, 1962). There is a slight increase in average grain size and a slight decrease in cementation toward the upper parts of the Navajo (Uygur, 1980), resulting in a corresponding slight upward increase in porosity and hydraulic conductivity (Freethey and Cordy, 1991). However, secondary permeability due to fractures is still the most important factor controlling the ability of the formation to yield water. The hydraulic conductivity derived from unfractured core samples of the Navajo in Emery County ranged from 0.0037 to 5.1 feet/day (Hood and Patterson, 1984). Based on oil well data, Hood and Patterson (1984) calculated that the hydraulic conductivity of an open 0.001-inch-wide fracture would be 132 feet/day. However, such a calculation overestimates the ability of a fractured-rock aquifer to yield water. The highest hydraulic conductivity calculated by Freethey and Cordy (1991) from aquifer tests was 88 feet/day for a 44-foot interval of fractured Navajo Sandstone, and values calculated from aquifer tests in Utah, Arizona, and Colorado were most commonly between 0.1 and 1.0 feet/day. For the Navajo aquifer in Grand County, estimated values for transmissivity range from nearly 0, where the Navajo pinches out in the east, to almost 700 square feet/day in the southwest; hydraulic conductivity ranges from as low as 0.4 feet/day in the northeast to 1 foot/day in the southwest (Jobin, 1962, in Blanchard, 1990).

Entrada Aquifer

The Entrada aquifer consists of the Jurassic Entrada Sandstone, which crops out extensively in the southern half of Grand County. The Entrada Sandstone has three members which yield variable amounts of ground water to seeps, springs, and wells.

The oldest member, the Dewey Bridge, consists of siltstone and fine-grained sandstone (Sumsion, 1971) and ranges in thickness from 40 to 240 feet in the Moab-Arches-La Sal area (Hintze, 1988). The Dewey Bridge Member commonly acts as a confining unit because it exhibits transmissivity and hydraulic conductivity values that are lower than those of the underlying and overlying rocks (Blanchard, 1990).

The Slick Rock Member is a medium-grained, massive, extensively cross-bedded eolian sandstone which typically weathers into steep cliffs and rounded slopes (Blanchard, 1990). The Slick Rock ranges in thickness from 200 to 500 feet in the Moab-Arches-La Sal area (Hintze, 1988) and is the principal aquifer of the Entrada Sandstone, commonly yielding fresh water in quantities of 5 gallons/minute or less to springs or seeps throughout its outcrop area (Blanchard, 1990).

The Moab Tongue (also called the Moab Member in some areas) is the youngest rock unit of the Entrada Formation, but is present as a mappable unit only in some areas of Grand County (Hintze, 1988). It is a fine-grained, cross-bedded sandstone with a white, yellow-orange, or light-pink-gray color (Blanchard, 1990) and ranges in thickness from 50 to 180 feet in the Moab-Arches-La Sal area (Hintze, 1988). The Moab Tongue acts more as a recharge unit, yielding less water overall than the Slick Rock Member (Blanchard, 1990). Where highly fractured the Moab Tongue has a high rate of infiltration and discharge.

The Entrada Sandstone is well exposed in Arches National Park, to the east of the park, and in the upper reaches of the Mill Creek drainage (Blanchard, 1990). Plate 4 shows the general area in Grand County where the Entrada Sandstone is present, and where the total thickness of overlying rock is greater than 2,000 feet (Freethey and Cordy, 1991). Springs and seeps typically discharge from the Entrada where vertical hydraulic conductivity decreases at contacts between cross-bed sets or at the top of the less permeable Dewey Bridge Member (Blanchard, 1990). Hydraulic conductivity values for the Entrada in Grand County range from an estimated 0.1 feet/day in the west to 1.1 feet/day in the east; transmissivity values range from an estimated 50 square feet/day in the west to more than 150 square feet/day in the east (Jobin, 1962, in Blanchard, 1990).

Morrison Aquifer

The Jurassic to Cretaceous Morrison Formation consists of mudstone, siltstone, sandstone, and conglomerate with thin limestone beds (Rush and others, 1982). The Morrison Formation consists of three members: from oldest to youngest, they are the Tidwell Member, the Salt Wash Member, and the Brushy Basin Member, and range in thickness in the Moab-Arches-La Sal area from 20 to 100, 130 to 350, and 250 to 450 feet, respectively (Hintze, 1988). Many springs issue from lenticular sandstone of the first two members (Rush and others, 1982) and therefore they may be potential aquifers in central Grand County. Plate 5 shows where these units are present, and where the total thickness of overlying rock is greater than 2,000 feet (Freethey and Cordy, 1991). The Brushy Basin Member is a confining unit (Freethey and Cordy, 1991).

Dakota Aquifer

Many springs discharge from the Dakota Sandstone and the Burro Canyon Formation, which comprise the Dakota aquifer, along the flanks of the La Sal Mountains (Weir, Maxfield, and Hart, 1983). Most wells along the south and west flanks of the La Sal Mountains also produce from the Dakota aquifer (Weir, Maxfield, and Hart, 1983). These Cretaceous formations may potentially yield water in other areas as well. The older Burro Canyon Formation consists of fine- to coarse-grained sandstone interbedded with siltstone, shale, mudstone, and limestone (Blanchard, 1990), and is 80 to 250 feet thick in the Moab-Arches-La Sal area (Hintze, 1988). The younger Dakota Sandstone consists of interbedded sandstone and conglomerate containing carbonaceous shale and coal (Rush and others, 1982), and is 0 to 200 feet thick in the Moab-Arches-La Sal area (Hintze, 1988). The springs issuing from the flanks of the La Sal Mountains have a large variation in flow rate, but are perennial with an average discharge rate of 18 gallons per minute (Weir, Maxfield, and Hart, 1983). Plate 6 shows the general area where the Dakota aquifer is present, and where the total thickness of overlying rock is greater than 2,000 feet.

Wasatch Aquifer

The Tertiary Wasatch Formation, which comprises the Wasatch aquifer (plate 7), is a potential aquifer and is known to yield water to springs along the Roan Cliffs in the northern part of Grand County. The Wasatch Formation consists of dark red sandstones and shales (Rush and others, 1982), and is 1,000 to 1,600 feet thick in the Cisco-Harley Dome area (Hintze, 1988). Blanchard (1990) reports a yield of about 30 gallons per minute from one spring in Grand County. Feltis (1966) reports a yield of 225 gallons per minute from a freshwater spring near the Green River in T. 16 S., R. 17 E., Salt Lake Base Line and Meridian, but we could not discern whether this spring is in Grand or Emery County.

Parachute Creek Aquifer

The Parachute Creek Member of the Tertiary Green River Formation crops out north of the Book Cliffs in the Uinta Basin (plate 7). The Green River Formation consists of marlstone and oil shale with some sandstone, siltstone, and tuff (Blanchard, 1990), and is 0 to 2,000 feet thick in the Cisco-Harley Dome area (Hintze, 1988). More than 50 springs in the area discharge between 1 and 20 gallons per minute (Blanchard, 1990). Since there is little development or need, few water wells have been drilled in the Parachute Creek aquifer

Unconsolidated Aquifers

Unconsolidated sediments, generally Pleistocene or Holocene in age (Sumsion, 1971), are found throughout the southern portion of Grand County (plate 8). The unconsolidated sediments are typically deposited as a thin veneer on bedrock, or as valley fill in the northwest-southeast-trending structural depressions. Except for the Spanish and Castle Valley areas, little information is available regarding the thickness of unconsolidated deposits in Grand County. Types of unconsolidated sediments include: wind-blown silt and sand, stream alluvium (including terrace gravels), alluvial-fan deposits, pediment-mantle deposits, talus, landslide deposits, colluvium, and glacial outwash and till.

These unconsolidated deposits generally consist of mixtures of sand, silt, gravel, and clay exhibiting varying degrees of stratification and sorting. Unconsolidated sediments have a wide range of hydrologic characteristics that vary primarily due to grain size, sorting, and bedding. Permeability and hydraulic conductivity generally increase with increased grain size and sorting. Wind-blown silt and sand deposits are commonly highly permeable because they are very well sorted. Stream alluvium may have a wide range of hydraulic characteristics because the deposits contain highly permeable stream-bed gravels and low-permeability overbank clays. Glacial till generally has a low permeability, primarily due to poor sorting.

Unconsolidated aquifers are an important source of ground water in both the Spanish and Castle Valley areas. Most of the residents of Grand County live in the Spanish Valley area; in 1987, about 5,000 people lived in Moab (Blanchard, 1990). The valley-fill deposits in Spanish Valley (which, as used here, includes the area in the northwest part of the valley that is sometimes referred to as Moab Valley) provide water that is used mostly for irrigation, but also for some domestic water supply (Steiger and Susong, 1997). The valley fill, predominately stream alluvium and alluvial-fan deposits, is up to 400 feet thick in northwestern Spanish Valley near the Colorado River (Doelling and others, 1995). The average thickness of saturated sediments in Spanish Valley is about 70 feet (Sumsion, 1971). Spanish Valley has over 200 wells completed in unconsolidated deposits (Sumsion, 1971); these wells range in depth from 30 to 300 feet (Gloyn and others, 1995; Lowe, 1996) and have water yields ranging from 8 to 1,000 gallons per minute (Sumsion, 1971). The average transmissivity for the Spanish Valley valley-fill aquifer is estimated at approximately 10,000 square feet/day (Sumsion, 1971).

Castle Valley has become a popular site for vacation and retirement homes built on 5-acre lots in recent years, with about 300 people residing in the valley in 1996 (Snyder, 1996a,b). Each residence has its own well and septic tank soil-absorption system. The valley-fill deposits in Castle Valley are the primary source of water for domestic use, and also provide some water for irrigation and stock watering (Snyder, 1996a,b). Unconsolidated sediments, predominantly stream alluvium and alluvial-fan deposits, are up to 350 feet thick in lower (northwestern) Castle Valley (Doelling and Ross, 1993). The Castle Valley valley-fill aquifer is under unconfined conditions, with the water table ranging from 30 to 100 feet below the ground surface (Snyder, 1996a,b). There were more than 100 wells in the Castle Valley valley-fill aquifer in 1987 (Blanchard, 1990); these wells are typically less than 150 feet deep (Snyder, 1996a,b)

RECHARGE

The fractured-rock aquifers all receive recharge through infiltration of precipitation and stream flow. The La Sal Mountains are a principal area of recharge for the bedrock aquifers in Grand County; the high mountain slopes are mantled in many areas by talus which readily absorbs snowmelt runoff and precipitation (Blanchard, 1990). Additionally, the upturned and heavily fractured sedimentary strata comprising the flanks of the La Sal Mountains are capable of receiving more recharge than is possible for strata which are not heavily fractured (Blanchard, 1990). Another important recharge area is the Book and Roan Cliffs and Tavaputs Plateau, which also receives a significant amount of precipitation (Rush and others, 1982). Recharge to bedrock aquifers also takes place due to seepage along intermittent and ephemeral stream channels, and from direct infiltration of precipitation where fractured-rock aquifers crop out, or where they are overlain by other fractured bedrock units or coarse unconsolidated deposits.

Recharge in the La Sal Mountains is ultimately the source of recharge to the unconsolidated aquifers in Spanish and Castle Valleys. For Spanish Valley, most of the recharge to the valley-fill aquifer is from springs and subsurface flow from the Glen Canyon Group sandstones, principally from the east side of the valley (Sumsion, 1971), and from direct precipitation and infiltration of water from Pack Creek and Kens Lake (Steiger and Susong, 1997). For Castle Valley, the principal source of recharge to the valley-fill aquifer is infiltration from Castle and Placer Creeks; some additional recharge comes from fractured bedrock units along the southwest margins of the valley, and from infiltration of precipitation and irrigation water (Snyder, 1996a,b).

GROUND-WATER-FLOW DIRECTION

Regional directions of ground-water flow in the upper fractured-rock hydrologic system are shown in figure 2. In the southeast portion of Grand County, ground water generally flows from the La Sal Mountains to the Colorado River. North of the Colorado River, however, movement is toward the Colorado River and the Green River with a ground-water divide separating the two. Ground-water flow in the unconsolidated aquifers of Spanish and Castle Valleys is generally toward the northwest (Sumsion, 1971; Snyder, 1996a,b).

DISCHARGE

Sources of discharge in Grand County include: outflow to the Colorado and Green Rivers; evapotranspiration by phreatophytes and hydrophytes; spring flow and seeps; consumptive

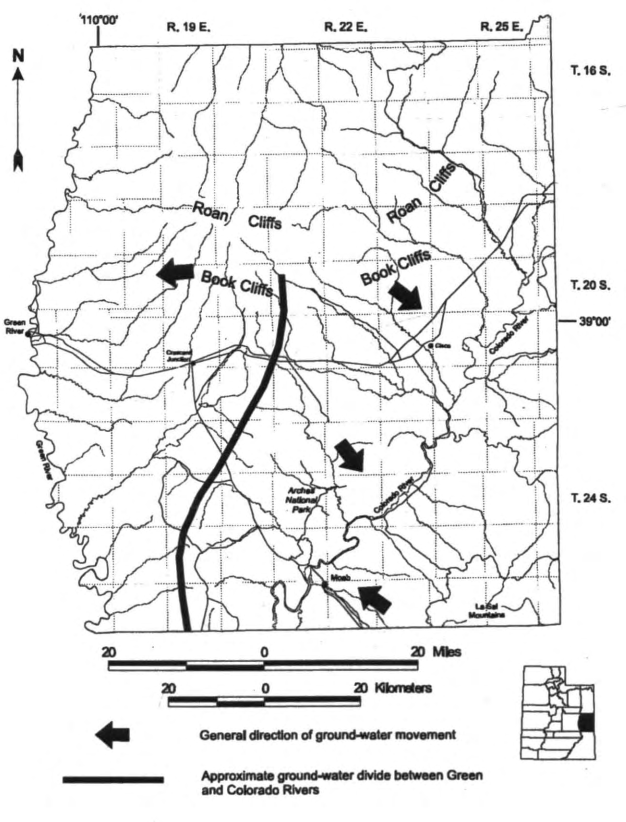

Figure 2. General direction of water movement in the upper ground-water system (from Blanchard, 1990).

use of ground water for irrigation, public supply, domestic purposes, and sewage treatment; and subsurface outflow (Sumsion, 1971; Rush and others, 1982; Weir, Maxfield, and Hart, 1983). Ground-water inflow to regional streams, especially the Colorado and Green Rivers, is the largest source of discharge followed in order of decreasing discharge by evapotranspiration, spring flow, consumptive use, and subsurface outflow.

The estimated ground-water inflow to the Colorado and Green Rivers in the Grand County area ranges from about 823 acre-feet/year per mile to about 3,703 acre-feet/year per mile of river channel (figure 3) (Rush and others, 1982). About 131 miles of the Green River flow along the western margin of Grand County, and about 85 miles of the Colorado River flow through Grand County. Assuming that the ground-water inflow to the Colorado River above the Cisco guage is at the same rate as from the Cisco guage to the confluence of the Colorado and Green Rivers, then about 315,000 acre-feet/year of ground water discharges to the Colorado River in Grand County. About 108,000 acre/feet of ground water discharges to the Green River along the western margin of Grand County, but a significant portion of this ground-water inflow is from Emery County aquifers.

Phreatophytes cover more than 46 square miles of Grand County (Rush and others, 1982; Weir, Maxfield, and Hart, 1983), of which 29 square miles is river floodplain; their total-average-annual discharge is over 40,000 acre-feet. Saltcedar, cottonwood, willow, and saltgrass are part of the riparian systems in the region, while areas with deeper water tables (up to about 50 feet) can support saltbrush, greasewood, and rabbitbrush. Evaporation from shallow water in soil is also a source of discharge.

In the La Sal Mountains, more than 200 perennial springs exist (most at an elevation above 7,500 feet), and 70 springs are present north of the Book Cliffs. Additionally, sporadic seeps and low-yield springs are found throughout Grand County, especially in the more permeable

Mesozoic rocks. Most seeps occur at the base of formations or along formation contacts where a canyon has been cut into the permeable rock units. In the many fractured-rock aquifers, water is commonly perched above less permeable formations which also help control the locations of seeps and springs.

Consumptive use of ground water is greatest in southern Grand County where the majority of people live. Unfortunately, the amount of ground water consumed versus surface water is not currently available. About 19,808 acre-feet/year of water is used to irrigate about 3,859 acres in Grand County (Utah Division of Water Resources, in preparation), likely mostly from surface-water diversion. A total of about 4,534 acre-feet/year of culinary (potable) water is used in Grand County: about 2,776 acre-feet/year is used for residential use, about 818 acre-feet/year is used for commercial/institutional purposes, and about 940 acre-feet/year is used for industrial purposes (Utah Division of Water Resources, in preparation). Additionally, about 704 acre-feet/year of secondary (non-potable) water is used for residential, commercial, and institutional purposes (Utah Division of Water Resources, in preparation). Much of the culinary water is likely from ground water (wells and springs).

Subsurface outflow of ground water from Grand County is probably minimal (Rush and others, 1982).

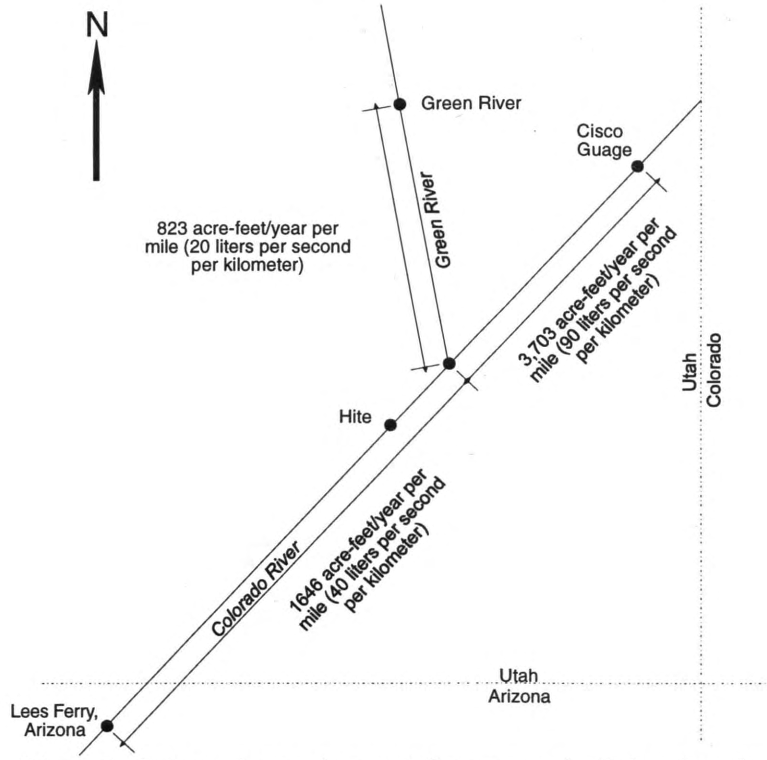

Figure 3*. Estimated ground-water inflow rate to the Colorado and Green Rivers (from Rush and others, 1982).*

WATER QUALITY

Water in recharge areas is generally fresh. Total-dissolved-solids concentrations generally increase with increasing depth or distance from recharge areas due to a greater opportunity to dissolve rock constituents with increased transit time and/or flow distance (Weir, Maxfield, and Hart, 1983). The amount and type of dissolved solids are also related to rock composition (abundance and solubility of various components) (Rush and others, 1982), so water in the Paradox Formation of the Hermosa Group usually has high chloride and total-dissolved-solids concentrations (table 1) due to the presence of highly soluble salt-bearing beds.

Water salinity is classified based on concentration of dissolved solids in milligrams per liter (mg/L) as follows: fresh, 0 to 1,000 mg/L; slightly saline, 1,000 to 3,000 mg/L; moderately saline, 3,000 to 10,000 mg/L; very saline, 10,000 to 35,000 mg/L; and briny, more than 35,000 mg/L. Ground water is classified, under drinking-water- and ground-water-protection regulations, based largely on total-dissolved-solids concentrations as shown in table 2. Class IA and II waters are considered suitable for drinking water, provided concentrations of individual constituents do not exceed state and federal ground-water-quality (health) standards. Class III water is generally suitable for drinking water only if treated, but can be used for some agricultural or industrial purposes without

Table 2. Drinking-water and ground-water-protection regulations in Utah (Snyder, 1996a).

CLASS	TOTAL DISSOLVED SOLIDS (milligrams per liter)	APPROXIMATE SPECIFIC CONDUCTANCE (micromhos per centimeter at 25°C)
IA (pristine)	less than 500	less than 750
II (drinking water quality)	500 to 3,000	750 to 4,700
III (limited use)	3,000 to 10,000	4,700 to 15,000
IV (saline)	more than 10,000	more than 15,000

treatment. Class IV water, though not suitable for drinking, may in some instances be mined for its dissolved minerals.

Fractured-Rock Aquifers

Lower Paleozoic Aquifer

Most of the water-quality data from the Lower Paleozoic aquifer are from petroleum wells where the formations are typically listed only as rocks of Mississippian age (Feltis, 1966); most of these data are from equivalents of the Leadville Limestone (Weir, Maxfield, and Hart, 1983). The total-dissolved-solids concentrations for water samples collected from Mississippian rocks in Grand County ranged from 7,172 to 379,469 mg/L (Feltis, 1966, table 3; Gwynn, 1995). The Leadville aquifer, based on water-quality information from Grand and San Juan Counties, typically contains sodium-chloride-type water with subordinate sulfate and potassium (Weir, Maxfield, and Hart, 1983; Gwynn, 1995).

Cutler Aquifer

Samples from two springs issuing from the White Rim Sandstone in Canyonlands National Park had total-dissolved-solids concentrations of 270 mg/L and 308 mg/L; samples from three wells producing from the White Rim Sandstone at Canyonlands had total-dissolved-solids concentrations ranging from 1,720 mg/L to 2,730 mg/L (Huntoon, 1977). The springs produce calcium-magnesium-bicarbonate- and calcium-magnesium-sodium-bicarbonate-type water; for the wells, water types were mixed and varied from sample to sample (Huntoon, 1977)

Blanchard (1990) reported that samples from three wells in the undifferentiated Cutler Formation near Castle Valley had total-dissolved-solids concentrations ranging from 1,420 mg/L to 3,450 mg/L, and that two of the wells exceeded the ground-water-quality (health) standard of 10 micrograms/liter for selenium. Ford and Grandy (1995) reported that water samples from the Cutler aquifer in Castle Valley had specific conductances ranging from 842 to 4,360 micromhos per centimeter at 25°C. However, Ford and Grandy (1995) did not find high selenium concentrations in any of the wells they sampled. The Cutler aquifer in Castle Valley typically contains calcium-magnesium-sulfate- or calcium-magnesium-sodium-sulfate-type water (Blanchard, 1990).

Wingate Aquifer

Rush and others (1982) reported that total-dissolved-solids concentrations for nine samples from the Wingate aquifer ranged from 164 to 680 mg/L, with an average of 260 mg/L. One sample from Salt Springs, which discharges from the base of the Wingate Sandstone, had an unusually high specific conductance of 3,760 micromhos per centimeter at 25°C, probably due to a long flow path in a regional flow system (Rush and others, 1982). Blanchard (1990) reported that three samples from springs issuing from the Wingate aquifer had total-dissolved-solids concentrations ranging from 161 to 174 mg/L, and that a sample from a 765-feet-deep well in Arches National Park had a total-dissolved-solids concentration of 280 mg/L. The Wingate aquifer typically produces calcium-magnesium-bicarbonate-type water; however, the sample from Jackson Reservoir Springs that produced the 680 mg/L value, was characterized as calcium-sulfate-type water (Weir, Maxfield, and Hart, 1983).

Navajo Aquifer

The Navajo aquifer generally produces water with low total-dissolved solids concentrations due to a low soluble-mineral content and because it has an extensive outcrop area in southern Grand County that receives recharge from direct infiltration of precipitation (Rush and others, 1982). Weir, Maxfield, and Hart (1983) reported that total-dissolved-solids concentrations for six samples collected from the Navajo aquifer ranged from 163 to 505 mg/L, and averaged 275 mg/L. Blanchard (1990) reported that water samples from five springs issuing from the Navajo aquifer in Grand County had total-dissolved-solids concentrations ranging from 102 to 385 mg/L, and that two wells completed in the Navajo aquifer had total-dissolved-solids concentrations of 210 and 360 mg/L. Steiger and Susong (1997) sampled wells from the Glen Canyon Group in the Spanish Valley area where the Glen Canyon aquifer generally contained water with total-dissolved-solids concentrations of less than 500 mg/L and where 69 percent of the Glen Canyon aquifer samples had total-dissolved-solids concentrations of less than 250 mg/L. The Navajo aquifer typically contains calcium-bicarbonate- or calcium-magnesium-bicarbonate-type water (Weir, Maxfield, and Hart, 1983; Blanchard, 1990).

Entrada Aquifer

Weir, Maxfield, and Hart (1983) reported that total-dissolved-solids concentrations for three samples collected from the Entrada aquifer ranged from 190 to 417 mg/L, and averaged 329 mg/L. Blanchard (1990) reported that water samples from six springs issuing from the Entrada aquifer in southern Grand County had total-dissolved-solids concentrations ranging from 119 to 157 mg/L, and that a flowing well completed in the Navajo aquifer in T. 24 S., R. 20 E., Salt Lake Base Line and Meridian, had a total-dissolved-solids concentration of 182 mg/L. The Entrada aquifer in southern Grand County typically contains calcium-carbonate-, calcium-magnesium-carbonate-, or magnesium-calcium-bicarbonate-type water (Blanchard, 1990). However, Feltis (1966) reported that total-dissolved-solids concentrations for samples collected from three oil test wells and one water well to the north in central and northeastern Grand County, where the top of the Entrada ranges in depth from 900 to 5,300 feet below land surface, ranged from 9,470 to 86,600 mg/L; the Entrada aquifer penetrated by these deep wells contains sodium-chloride-type water (Blanchard, 1990). These data indicate that while the Entrada aquifer typically contains fresh water in and near outcrop areas, ground-water salinity increases vertically with depth in the Entrada Sandstone, and laterally with distance from the recharge area. Blanchard (1990) concluded that these data indicate that fresh water is likely present only for a short distance north of the Entrada outcrop area.

Morrison Aquifer

Feltis (1966) reported that five Grand County wells completed in the Morrison aquifer produce water samples that had total-dissolved-solids concentrations ranging from 2,090 to 25,700 mg/L. A sixth Grand County well yielded a sample with a total-dissolved-solids concentration of 517 mg/L; Feltis (1966) speculated that recharge to the Morrison aquifer is at or near this well site. Water samples from two mines in the Morrison Formation in Grand County had total-dissolved-solids concentrations of 1,430 and 759 mg/L (Feltis, 1966).

Dakota Aquifer

Weir, Maxfield, and Hart (1983) reported that total-dissolved-solids concentrations for four samples collected from the Dakota aquifer ranged from 98 to 504 mg/L, and averaged 329 mg/L; they attributed the freshness of the water to the close proximity to the recharge area. These samples contained calcium-bicarbonate-type water (Weir, Maxfield, and Hart, 1983).

Wasatch Aquifer

Conroy and Fields (1977) reported that a Wasatch aquifer spring in Grand County had a total-dissolved-solids concentration of about 600 mg/L. Feltis (1966) reported that the spring issuing from the Wasatch Formation near the Green River produced a sample with a total-dissolved-solids concentration of 596 mg/L, but we could not determine if this spring is in Grand or Emery County. Smaller springs with similar water quality probably discharge from the Wasatch Formation along the Roan Cliffs escarpment.

Parachute Creek Aquifer

Conroy and Fields (1977) reported that 12 springs issuing from the Parachute Creek aquifer had total-dissolved-solids concentrations of less than 500 mg/L. Gwynn (1995), however, reports a few springs with total-dissolved-solids concentrations up to 800 mg/L. The springs typically produced calcium-magnesium-bicarbonate-type water, although some samples had mixed water types as well (Blanchard, 1990).

Unconsolidated Aquifers

In Spanish Valley, which has the largest unconsolidated aquifer in Grand County, Sumsion (1971) reported samples collected from nine wells had total-dissolved-solids concentrations ranging from 169 to 1,020 mg/L. Steiger and Susong (1997) reported that samples from 20 wells completed in the unconsolidated aquifer in Spanish Valley had total-dissolved-solids concentrations ranging from 260 to 1,820 mg/L, but that about 86 percent of the samples had total-dissolved-solids concentrations of less than 1,000 mg/L. The Spanish Valley unconsolidated aquifer generally yields calcium-bicarbonate-type or calcium-sulfate-bicarbonate-type ground water (Sumsion, 1971). The water in the Spanish Valley unconsolidated aquifer is generally of poorer quality than water in the Glen Canyon aquifer (Steiger and Susong, 1997), and mixing of water from this fractured-rock aquifer tends to decrease total-dissolved-solids concentrations in the unconsolidated aquifer as ground water in the valley fill flows from southeast to northwest (Sumsion, 1971). Sumsion (1971) reported nitrate concentrations in the Spanish Valley unconsolidated aquifer of up to 26 mg/L, more than twice the ground-water-quality (health) standard of 10 mg/L. Steiger and Susong (1997) reported that dissolved nitrate plus nitrite concentrations for ground water in Spanish Valley ranged from 0.04 to 5.87 mg/L, and attributed nitrate plus nitrite concentrations of greater than 3 mg/L in an area in the central portion of the valley to possibly be the result of human activities. This is an area where domestic waste water is or, until recently, was disposed of using septic tank soil-absorption systems.

In Castle Valley, Ford and Grandy (1995) reported that specific-conductance values for samples from eight unconsolidated aquifer wells ranged from 357 to 1,960 micromhos per centimeter at 25°C. There is a general down-valley increase in total-dissolved-solids concentrations in the Castle Valley unconsolidated aquifer (Weir, Maxfield, and Hart, 1993). Snyder (1996a,b) attributed this down-valley increase in total-dissolved-solids concentrations in the unconsolidated aquifer to recharge from the Cutler and Paradox Formations which contain poorer quality water. Ford and Grandy (1995) reported nitrate concentrations of less than 1 mg/L for samples from wells in the Castle Valley unconsolidated aquifer.

SUMMARY

In Grand County, ground water has been withdrawn during this century primarily from two types of aquifers: fractured rock and unconsolidated deposits. Some of the better water-yielding rock units are grouped together into nine aquifers. From oldest to youngest (in order of decreasing depth at any given location), these aquifers are the Lower Paleozoic aquifer, the Cutler aquifer, the Wingate aquifer, the Navajo aquifer, the Entrada aquifer, the Morrison aquifer, the Dakota aquifer, the Wasatch aquifer, and the Parachute Creek aquifer.

The Navajo Sandstone is the shallowest and most permeable formation in the Glen Canyon Group, and is therefore the target for most bedrock wells drilled in southern Grand County. The Glen Canyon Group is the principal source of drinking water in the Moab and Spanish Valleys area of southern Grand County. The Navajo aquifer generally produces water with low total-dissolved-solids concentrations in southern Grand County because it has a low soluble-mineral content and because it has an extensive outcrop area that receives recharge from direct infiltration of precipitation.

Unconsolidated aquifers are an important source of ground water in both the Spanish and Castle Valley areas. In Spanish Valley, total-dissolved-solids concentrations range from 169 to 1,820 mg/L, but about 86 percent of the wells sampled have total-dissolved-solids concentrations of less than 1,000 mg/L. Nitrate concentrations as high as 26 mg/L have been reported in Spanish Valley; nitrate plus nitrite concentrations of greater than 3 mg/L in an area in the central portion of the valley may possibly be the result of human activities. In Castle Valley, specific-conductance values range from 357 to 1,960 micromhos per centimeter at 25°C, and nitrate concentrations are less than 1 mg/L for samples from wells in the unconsolidated aquifer.

The fractured-rock aquifers all receive recharge through infiltration of precipitation and stream flow, especially in the La Sal Mountains and Book Cliffs. For Spanish Valley, most of the recharge to the valley-fill aquifer is from springs and subsurface flow from the Glen Canyon Group sandstones, and from direct precipitation and infiltration of water from Pack Creek and Kens Lake. For Castle Valley, the principal source of recharge to the valley-fill aquifer is infiltration from Castle and Placer Creeks; some additional recharge comes from fractured bedrock units and from infiltration of precipitation and irrigation water.

Sources of discharge in Grand County include: outflow to the Colorado and Green Rivers; evapotranspiration by phreatophytes and hydrophytes; spring flow and seeps; consumptive use of ground water for irrigation, public supply, domestic purposes, and sewage treatment; and subsurface outflow. Ground-water inflow to regional streams, especially the Colorado and Green Rivers, is the largest source of discharge followed in order of decreasing discharge by evapotranspiration, spring flow, consumptive use, and subsurface outflow.

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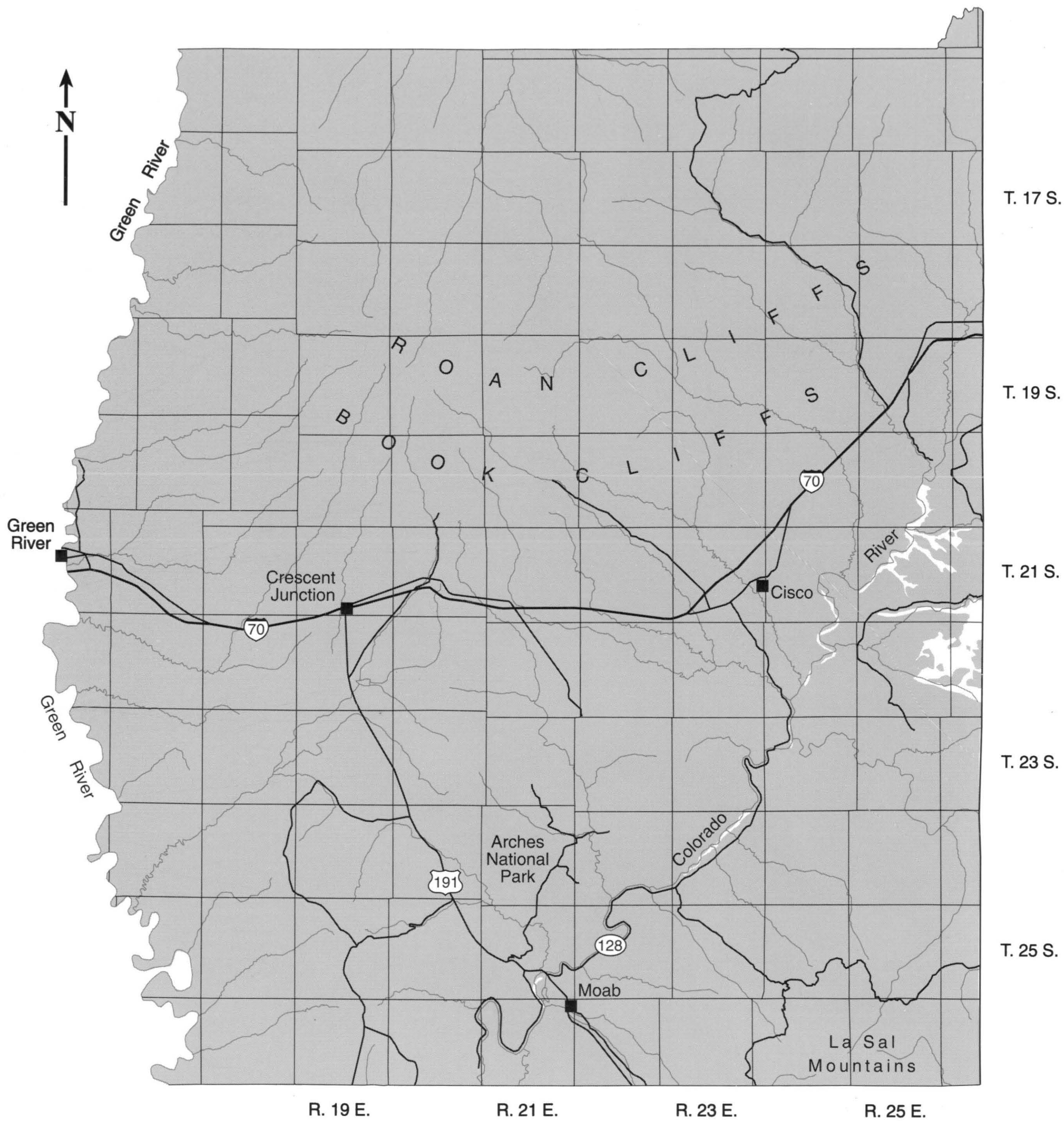
Plate 1. Areal Extent of the Lower Paleozoic Aquifer

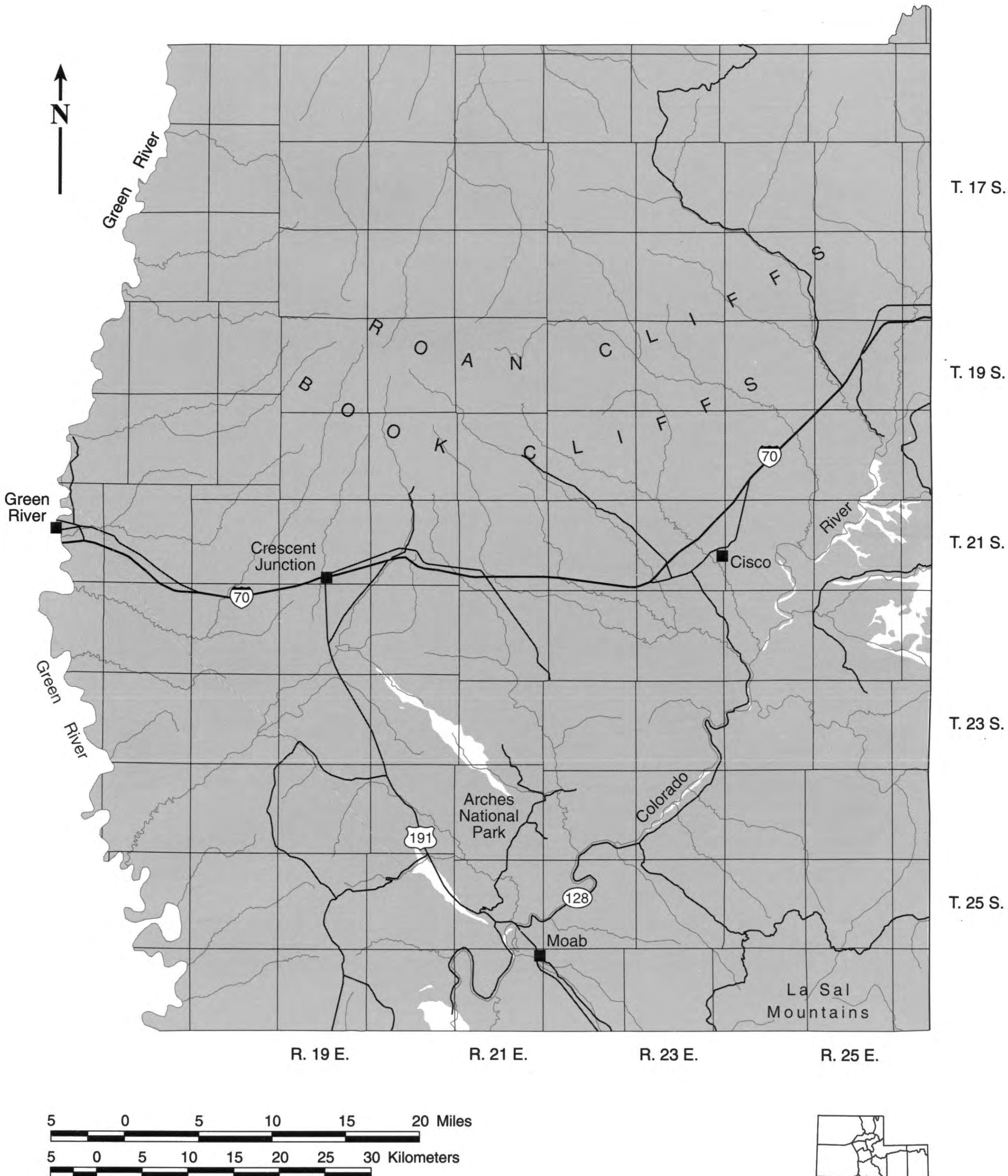


5 0 5 10 15 20 Miles

5 0 5 10 15 20 25 30 Kilometers

Areas underlain by the Lower Paleozoic Aquifer

Plate 2. Areal Extent of the Cutler Aquifer



Areas underlain by the Cutler Aquifer

Plate 3. Areal Extent of the Navajo and Wingate Aquifers

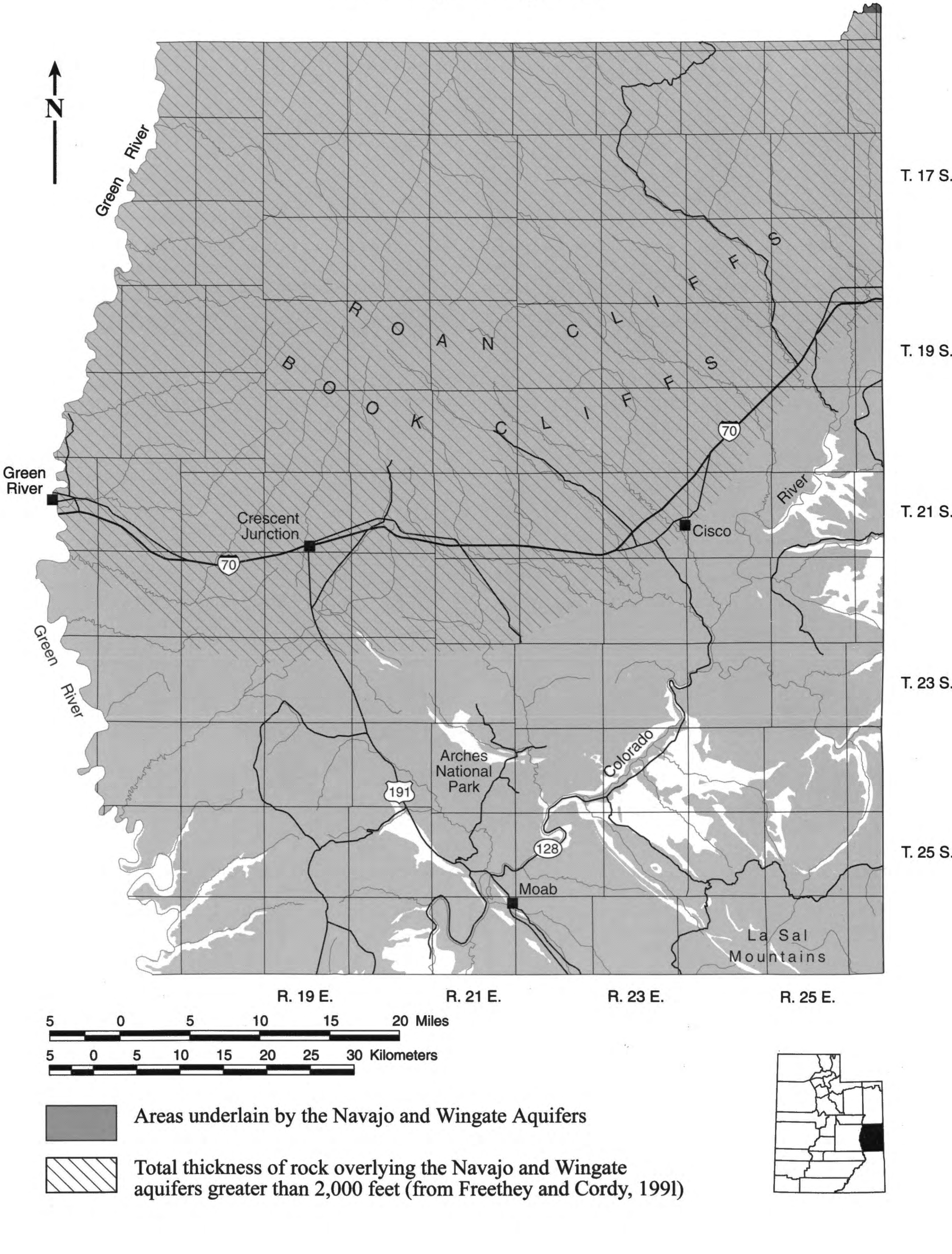
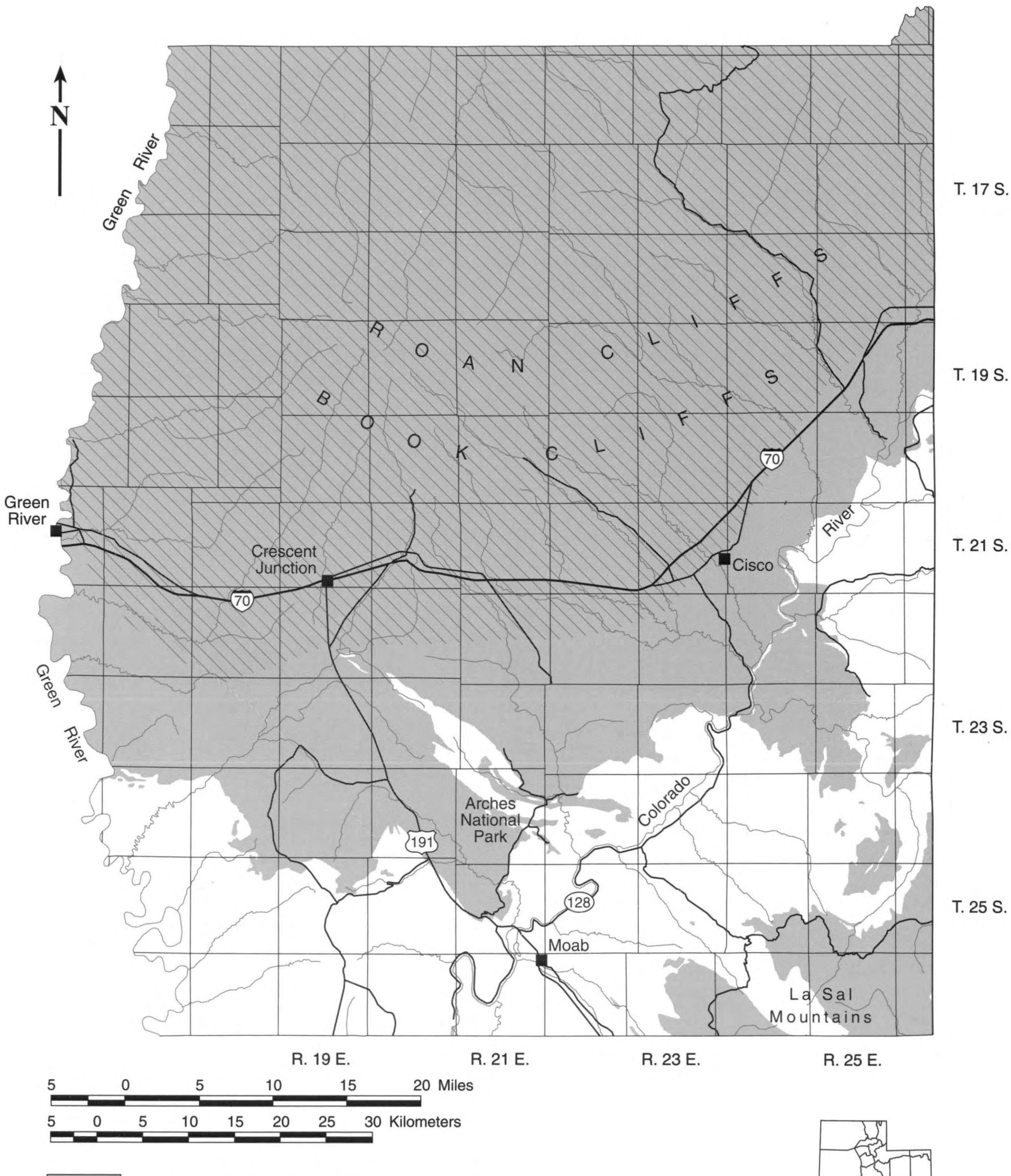


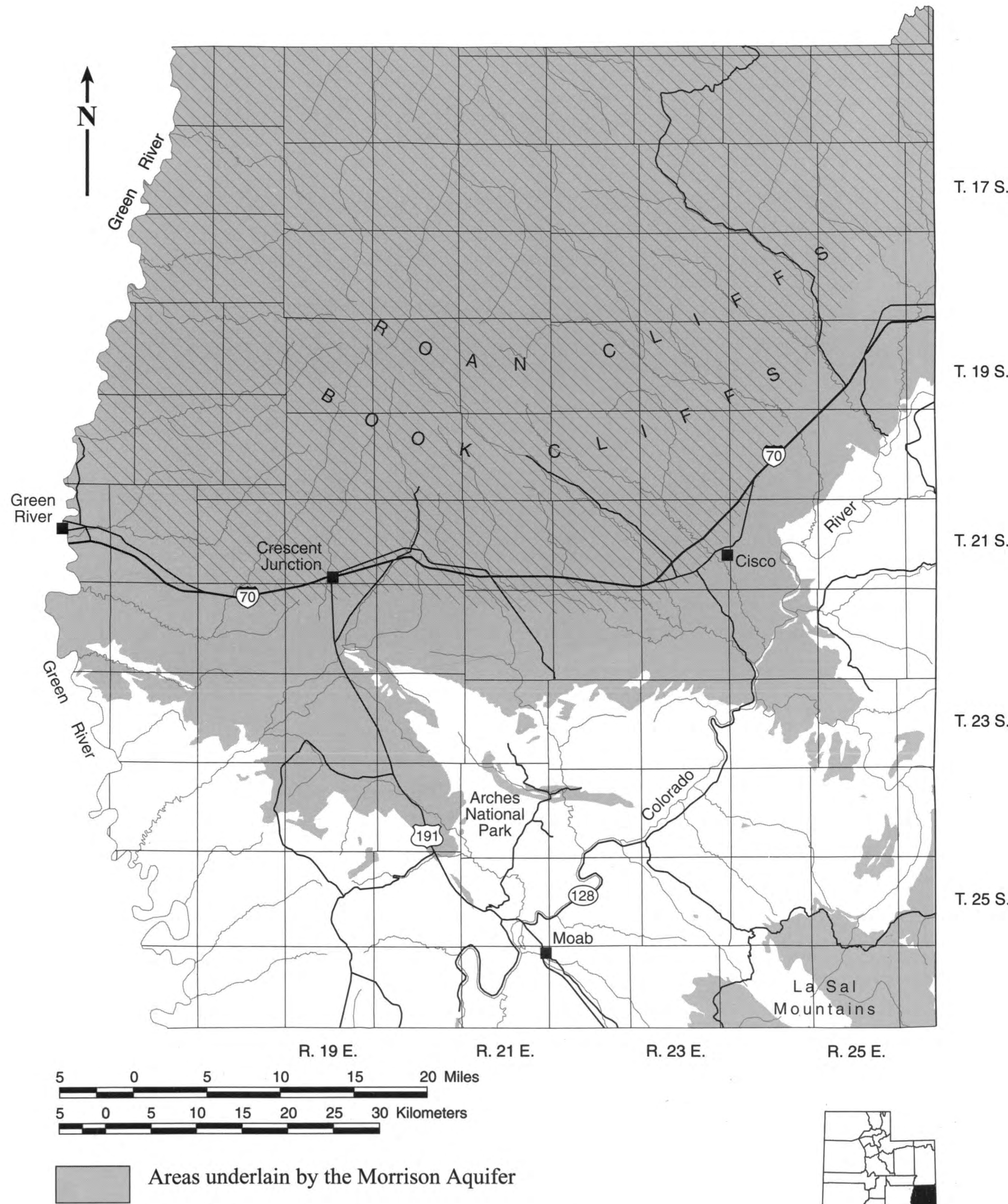
Plate 4. Areal Extent of the Entrada Aquifer



Areas underlain by the Entrada Aquifer

Total thickness of rock overlying the Entrada Aquifer greater than 2,000 feet (from Freethey and Cordy, 1991)

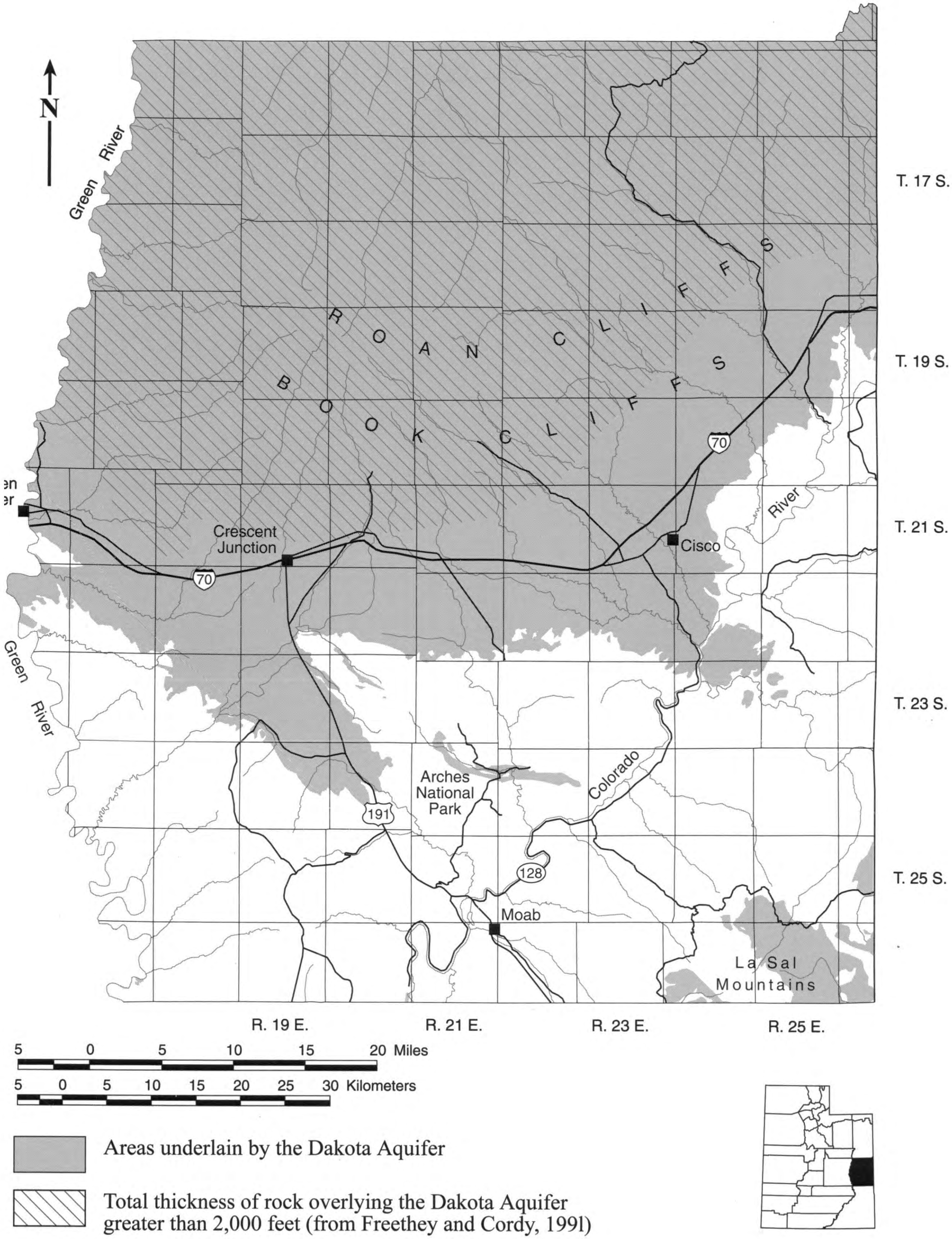
Plate 5. Areal Extent of the Morrison Aquifer



Areas underlain by the Morrison Aquifer

Total thickness of rock overlying the Morrison Aquifer greater than 2,000 feet (from Freethey and Cordy, 1991)

Plate 6. Areal Extent of the Dakota Aquifer



Areas underlain by the Dakota Aquifer

Total thickness of rock overlying the Dakota Aquifer greater than 2,000 feet (from Freethey and Cordy, 1991)

Plate 7. Areal Extent of the Parachute Creek and Wasatch Aquifers

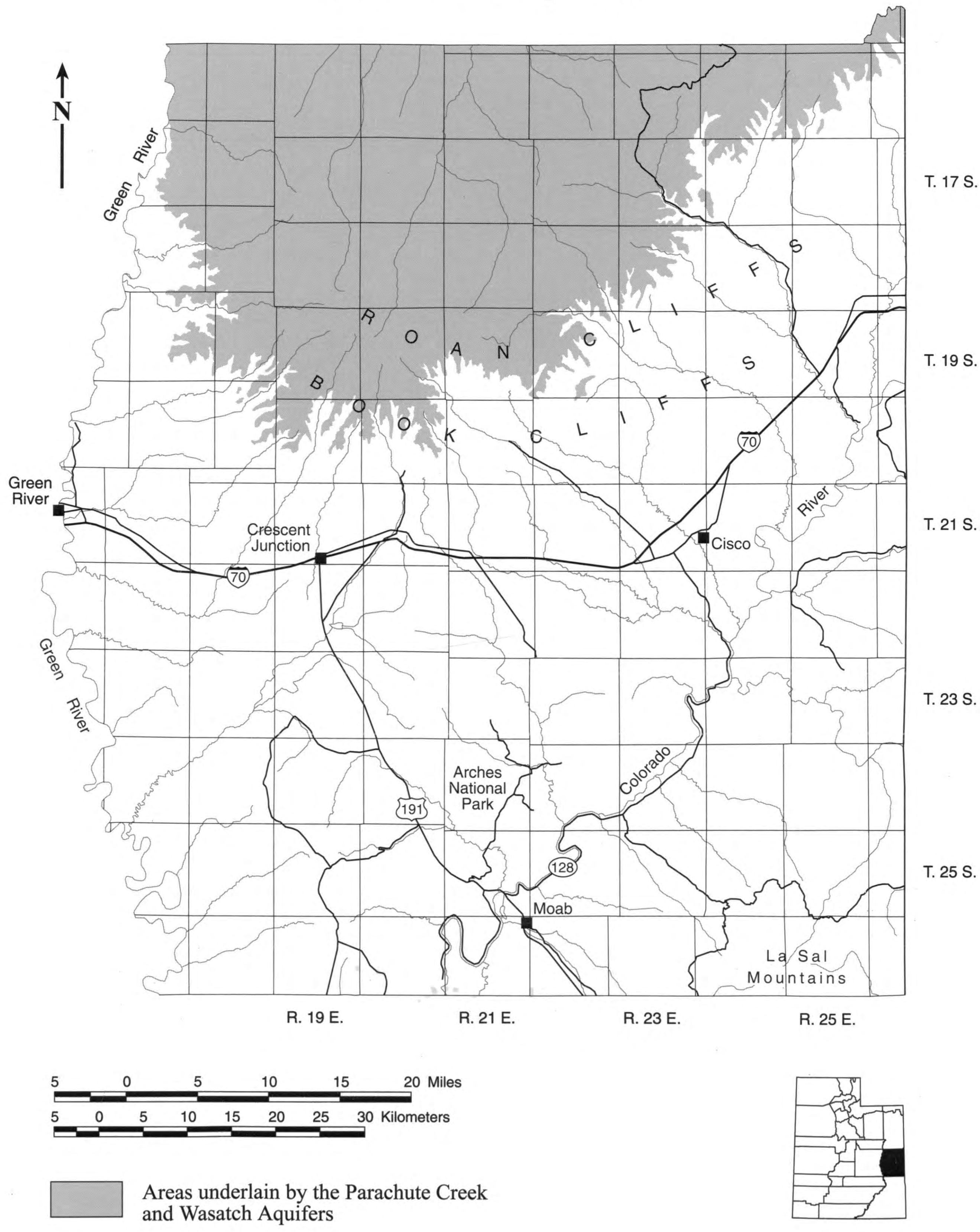


Plate 8. Areal Extent of Potential Unconsolidated Aquifers