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Geology and Groundwater Resources of Douglas County, Colorado

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Daniels Park, view northwest, Douglas County, Colorado. Photo credit: Peter Barkmann.

TABLE OF CONTENTS

TABLE OF CONTENTS	i
LIST OF TABLES	ii
LIST OF FIGURES	ii
LIST OF PLATES	ii
ACKNOWLEDGMENTS.....	iii
ABSTRACT	iv
INTRODUCTION.....	1
GENERAL GEOLOGY OF DOUGLAS COUNTY	2
REGIONAL SETTING.....	2
MAJOR ROCK UNITS AND STRATIGRAPHY	2
Precambrian Igneous and Metamorphic Rocks.....	5
Paleozoic Sedimentary Units.....	5
Mesozoic Sedimentary Units.....	8
Cretaceous and Tertiary Laramide Sedimentary Units	8
Post-Laramide Volcanic and Sedimentary Units	10
Quaternary Unconsolidated Deposits	10
STRUCTURAL GEOLOGY.....	11
Rampart Range Fault Zone.....	11
Front Range Uplift.....	11
Denver Basin	13
Other Structural Features	13
GROUNDWATER IN DOUGLAS COUNTY	14
FRACTURED CRYSTALLINE ROCK AQUIFERS.....	15
Precambrian Igneous Rocks	15
Precambrian Metamorphic Rocks	15
SEDIMENTARY BEDROCK AQUIFERS AND CONFINING UNITS	16
Older Paleozoic Unit.....	16
Lyons-Fountain Aquifer	17
Triassic-Jurassic Unit	17
Dakota Aquifer	17
Cretaceous Marine Shale Unit	18
Laramie-Fox Hills Aquifer	18
Laramie Formation.....	19
Denver Basin Group Hydrogeologic Units	19
Post-Laramide Hydrogeologic Units	23
ALLUVIAL AQUIFERS	23
OTHER NEAR-SURFACE GROUNDWATER.....	24

REFERENCES..... 25**PLATES (Appended to Report PDF)****TABLES**

Table 1	Geologic maps covering Douglas County	4
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FIGURES

Figure 1	Regional location map of Douglas County.....	3
Figure 2	Stratigraphic column showing units address in this study:	
	2a - Quaternary through Lower Cretaceous units	6
	2b - Jurassic through Precambrian units	7
Figure 3	Structural features of Douglas County	12
Figure 4	Typical geophysical log, Fox Hills Sandstone through Dawson Arkose.....	20

PLATES

Plate 1	Geologic Map of Douglas County	Appended
Plate 2	Cross section through Douglas County.....	Appended
Plate 3	Precambrian crystalline bedrock extent map	Appended
Plate 4	Older Paleozoic sedimentary unit extent map	Appended
Plate 5	Older Paleozoic sedimentary unit depth map	Appended
Plate 6	Lyons-Fountain aquifer extent map.....	Appended
Plate 7	Lyons-Fountain aquifer depth map	Appended
Plate 8	Dakota Group aquifer extent map.....	Appended
Plate 9	Dakota Group aquifer depth map.....	Appended
Plate 10	Laramie-Fox Hills aquifer extent map	Appended
Plate 11	Laramie-Fox Hills aquifer depth map.....	Appended
Plate 12	D1 Lower Fan extent map	Appended
Plate 13	D1 Lower Fan depth map	Appended
Plate 14	D1 Middle Unit extent map.....	Appended
Plate 15	D1 Middle Unit depth map.....	Appended
Plate 16	D1 Upper Fan extent map	Appended
Plate 17	D1 Upper Fan depth map	Appended
Plate 18	Dawson Arkose aquifer depth map	Appended
Plate 19	Dawson Arkose aquifer depth map	Appended
Plate 20	Alluvial aquifer and bedrock elevation map	Appended

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Many people contributed to this project indirectly over the years. Development of the generalized geologic map builds on many hours of field mapping by CGS and USGS geologists.



Eocene Castle Rock Conglomerate showing trough cross-bedding, with former storage facility in Prairie Canyon Ranch. Photo credit: Steve Keller, April 2016.

ABSTRACT



Douglas County has experienced considerable population growth in recent decades with development becoming increasingly reliant on local groundwater resources. A diverse geologic setting characterizes the County and groundwater can be found in many different geologic settings. This report compiles the most recent geologic mapping and interpretations focusing on groundwater occurrences in the various geologic formations found in the area.

Douglas County straddles the transition from the rugged Front Range of the Rocky Mountains to the gentler Colorado Piedmont. Locally, the Rampart Range is part of the Front Range as it crosses the region. A network of streams carves deep canyons throughout the mountainous area, and the western boundary of the County follows the South Platte River canyon where it bisects the Rampart Range. The southern boundary of the County follows the Palmer Divide, which separates the South Platte and Arkansas River basins.

The Denver Basin is an asymmetric bowl-shaped structural depression on the east side of the Front Range. Sedimentary material shed from the rising Front Range uplift during the Laramide mountain building event filled the basin as it developed. Precambrian crystalline basement, which is at the surface in the Front Range, drops to 14,000 to 15,000 feet below the surface at its greatest depth near Castle Rock (Hemborg, 1996).

The transition between the Denver Basin and Rampart Range is a complex faulted and folded zone varying in width from less than one half mile to over five miles, known as the Rampart Range fault zone. Along many segments, it places the uplifted Precambrian rocks directly against Tertiary sediments of the Denver Basin. In other

places, Paleozoic and Mesozoic sedimentary units older than the Denver Basin sediments have been brought up to the surface within the zone, forming the venerable hog-back backdrop.

Precambrian igneous and metamorphic rocks, ranging in age from 1.8 to 1.1 billion years, are exposed at the surface, or can be found near the surface, in the Rampart Range on the western side of the County. Paleozoic sedimentary rocks underlie several areas of the County. Cambrian through Mississippian sedimentary rocks occur in three non-contiguous areas of Douglas County. Two are found along the Rampart Range fault and the third is within the Rampart Range in a small fault-bound block in the Trout Creek Valley.

Tectonic activity from Late Mississippian through Permian resulted in the development of a series of uplifts and downwarps throughout the region. On the east flank of the Front Range Uplift, the clastic sediments derived from erosion of the Paleozoic uplift are preserved.

Triassic and Jurassic sedimentary units mark a period of tectonic quiescence for the region prior to encroachment of the Cretaceous Interior Seaway. Sediments deposited during this time are exposed along the Rampart Range fault zone in the Roxborough Park and Perry Park areas. Encroachment of the Cretaceous Interior Seaway (Seaway) is marked by deposition of the Dakota Group in the Denver Basin. Volumetrically, marine shale of the dominates the group of sediments above the Dakota Group, referred to as the Cretaceous Seaway units, and thicknesses range from over 5,500 to 6,800 feet. The Fox Hills Sandstone was deposited in near-shore and beach environments of the retreating Interior Seaway. Eastward

retreat of the Seaway caused individual overlapping sandstone bodies to climb up-section and become progressively younger to the east. Overbank shale interbedded with lenticular beds of sandstone was deposited on a low-relief coastal plain following the retreat of the Interior Seaway. Late Cretaceous, Paleogene, and Eocene sediments record the evolution of the Laramide uplift throughout the Rocky Mountain region. During this period of uplift, a series of Precambrian basement-core blocks rose to the surface while basins subsided between and flanked the blocks. Clastic sediments shed off of the rising blocks accumulated in the intervening basins. Concurrent igneous activity contributed volcanic material to the sedimentary basin fill.

The region continued to be modified by tectonism after the primary Laramide uplift event. Overlying much of the bedrock are Quaternary unconsolidated sediments.

Based on differences in hydrologic properties, aquifers and confining units in Douglas County can be grouped into the following categories:

1. Fractured crystalline rock aquifers
 - Precambrian igneous and metamorphic rocks
2. Sedimentary bedrock aquifers and confining units
 - Paleozoic hydrogeologic units
 - Triassic-Jurassic unit
 - Dakota Group Aquifer
 - Cretaceous marine shale unit
 - Laramie-Fox Hills Aquifer
 - Denver Basin Group hydrogeologic units, which includes the D1 lower fan (DWR Arapahoe Aquifer), D1 middle unit (DWR Denver Aquifer), D1 upper fan (DWR Lower Dawson Aquifer), and Dawson Arkose (Upper Dawson Aquifer)
 - Post-Laramide units
3. Alluvial aquifer.

Maps for each of these units show the aerial extent across the County estimated by surface mapped outcrop patterns projected into the subsurface using interpretations of structural relationships. The maps also include locations of permitted water wells estimated to be completed in each unit. There were 7,667 water wells inventoried in Douglas County as of February 2013.

Aquifer-specific groundwater flow patterns in Douglas County are complex, given the variety of aquifer types, structural complexity, and topographic expression. However, generalizations can be made that provide insight into the overall water budget of the region, and to understand the potential as well as limitations of the resource. In simple

terms, the groundwater flow regime is a function of recharge, storage, flow pathways, and discharge. Generally, groundwater flows from areas where precipitation is high (along the Rampart Range toward the main river drainages).

Recharge to aquifers within Douglas County occurs through infiltration of precipitation from upland areas or where the aquifer is exposed, return flow from irrigation, seepage from surface water features, and through subsurface flow from adjacent hydrogeologic units.



Castle Rock Conglomerate showing fining upward sequence on north side of Lake Gulch Trail in Castlewood Canyon State Park, April 2016. Photo credit: Steve Keller.

INTRODUCTION



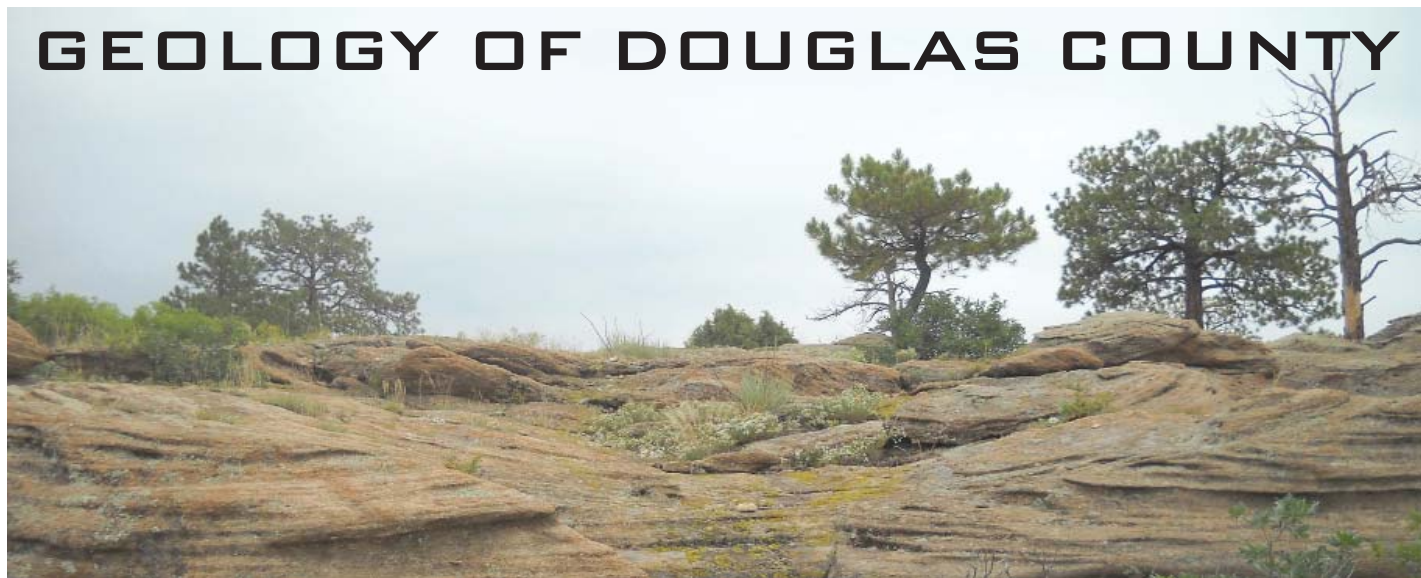
Douglas County has experienced considerable population growth in recent decades with development becoming increasingly reliant on local groundwater resources. A diverse geologic setting characterizes the County and groundwater can be found in many different geologic settings. This report compiles the most recent geologic mapping and interpretations focusing on groundwater occurrences in the various geologic formations found in the area. It has been prepared as an electronic-based product with the general public in mind, although it contains detailed background to be beneficial to more technical users.

The intent is to create a framework that illustrates the variety of geologic formations and how groundwater resources fit in the many geologic settings across the County. Because of the regional nature of this effort, detailed specifics are not presented. Aquifer specifics would require site-specific data and interpretation. For many aquifers and areas site-specific data simply are not available in the public domain. This effort should help guide future data gathering efforts that would be very useful for detailed assessments on an aquifer-by-aquifer and area-by-area basis.



South Platte River separating Douglas (left) and Jefferson (right) Counties. Burn scar from the 2002 Hayman Fire visible.
Photo credit: Larry Scott, October 2010

GEOLOGY OF DOUGLAS COUNTY



REGIONAL SETTING

Douglas County straddles the transition from the rugged Front Range of the Rocky Mountains to the gentler Colorado Piedmont (**Figure 1**). Locally, the Rampart Range is part of the Front Range as it crosses the region. This rugged wooded highland reaches elevations of up to 9,800 feet above mean sea level (MSL) at Devils Head and Thunder Butte. A network of streams carves deep canyons throughout the mountainous area and the western boundary of the County follows the South Platte River canyon where it bisects the Rampart Range. In contrast, the Colorado Piedmont, which flanks the Rampart Range, is characterized by lower relief buttes, mesas and open valleys. Tributaries to the South Platte River follow the valleys to the north and the Arkansas River to the south, carving a landscape into Upper Cretaceous and Tertiary strata. The southern boundary of the County follows the Palmer Divide, which separates the South Platte and Arkansas River basins. This high divide preserves the most complete thickness of Upper Cretaceous and Tertiary strata where least eroded. Several tributaries to the South Platte River, including Cherry Creek and Plum Creek, originate in the southern and western parts of the County, respectively.

Resistant Precambrian crystalline metamorphic and igneous rocks form the Rampart Range. These 1.1- to 1.7-billion year old rocks were brought to the surface during the Laramide mountain building event between approximately 75 and 50 million years ago [Ma] (Weimer, 1996). They form the core of an uplifted block that extends over 175 miles from the Colorado-Wyoming border south

to the Pikes Peak mountain complex. The uplifted block extends west to form the east side of South Park in Park County.

The Denver Basin is an asymmetric bowl-shaped structural depression on the east side of the Front Range. Sedimentary material shed from the rising Front Range uplift during the Laramide mountain building event filled the basin as it developed. Precambrian crystalline basement, which is at the surface in the Front Range, drops to 14,000 to 15,000 feet below the surface at its greatest depth near Castle Rock (Hemborg, 1996). To the north the Denver Basin is separated from the Cheyenne Basin by the Greeley Arch; to the south, it is separated from the Raton Basin by the Apishapa Arch.

The transition between the Denver Basin and Rampart Range is a complex faulted and folded zone varying in width from less than one half mile to over five miles, known as the Rampart Range fault zone. Along many segments, it places the uplifted Precambrian rocks directly against Tertiary sediments of the Denver Basin. In other places, Paleozoic and Mesozoic sedimentary units older than the Denver Basin sediments have been brought up to the surface within the zone, forming the venerable hog-back backdrop.

MAJOR ROCK UNITS AND STRATIGRAPHY

This effort incorporates results of mapping at different scales from many sources, spanning decades of work by

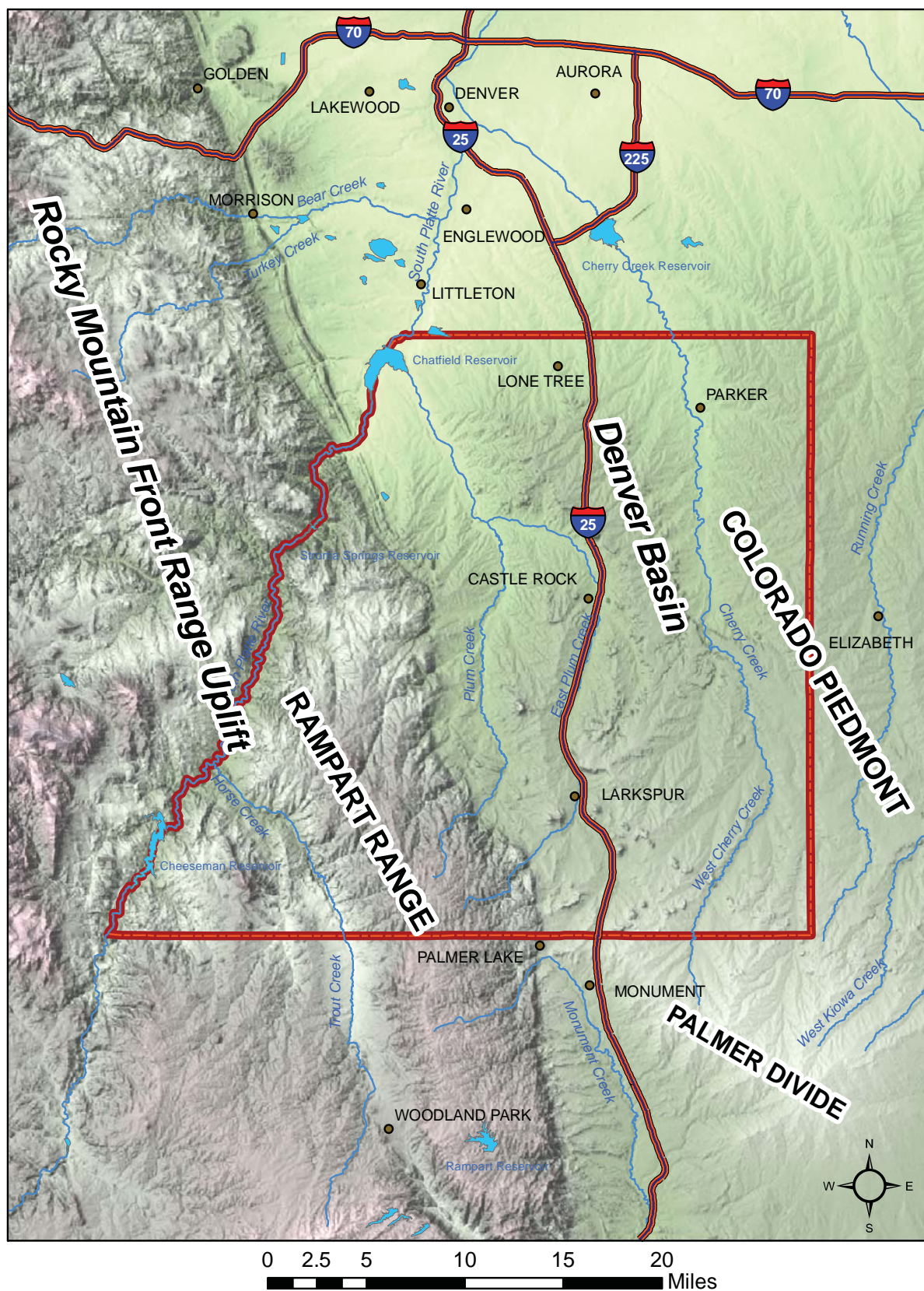


FIGURE 1. REGIONAL LOCATION MAP OF DOUGLAS COUNTY. Douglas County straddles the transition from the Rampart Range to the Colorado Piedmont physiographic provinces. This transition reflects a boundary in major geologic structural features. The Rocky Mountain Front Range structural uplift to the west rises above the Denver Basin downwarp on the east.

TABLE 1. GEOLOGIC MAP SOURCES.

Map Name	Authors	Scale	Published
Castle Rock North	Thorson	1:24,000	2005
Castle Rock South	Thorson	1:24,000	2004a
Cherry Valley School	Thorson	1:24,000	2004b
Dakan Mountain	Temple and others	1:24,000	2008
Dawson Butte	Morgan and others	1:24,000	2004
Greenland	Thorson and Himmelreich	1:24,000	2002
Highlands Ranch	Maberry and Lindvall	1:24,000	1977
Kassler	Scott	1:24,000	1963a & b
Larkspur	Thorson and others	1:24,000	2008
Littleton	Scott	1:24,000	1962
Parker	Maberry and Lindvall	1:24,000	1973
Platte Canyon	Peterson	1:24,000	1964
Ponderosa Park	Thorson	1:24,000	2007
Russellville Gulch	Thorson	1:24,000	2006
Sedalia	Morgan and others	1:24,000	2005
Upper Cretaceous, Paleocene and Eocene Strata in the Southwestern Denver Basin	Thorson	1:50,000	2011
West Edge of Denver Basin	Van Slyke	1:50,000	1996
Greater Denver	Trimble and Machette	1:100,000	1979
Bailey	Ruleman and others	1:100,000	2011

many authors. **Table 1** lists spatial data sources grouped by mapping scales. Primary sources consist of recent 1:24,000 quadrangle geologic maps produced by the CGS National Cooperative STATEMAP program and the USGS 1:100,000 (30' X 60') quadrangle series. Data from older or smaller scale maps have been used to fill in where detailed mapping was unavailable. **Plate 1** is a generalized geologic map of the County compiled from these multiple sources. **Plate 2** is a southwest to northeast cross section through the County illustrating the three-dimensional relationship of the varied rock types in the diverse structural setting found in the region.

Over the years geologic mapping has expanded upon and enhanced the understanding of the origins of the many units present in the Denver Basin. Nomenclature of the geologic units found in the region has changed through this evolution in geologic interpretation. This study uses the most recent nomenclature as published in the public domain, as shown in the stratigraphic column in Figure 2 (divided into **Figures 2a and 2b**). The following discussion groups formations by major geologic settings that led to similar enough formation characteristics to simplify the geologic setting with respect to groundwater resources and energy resources. For greater detail, refer to the original maps listed in Table 1 and included in the references.

PRECAMBRIAN IGNEOUS AND METAMORPHIC ROCKS

Precambrian igneous and metamorphic rocks are exposed at the surface, or can be found near the surface, in the Rampart Range on the western side of the County. These basement rocks consist of 1.7- to 1.8-billion year old biotite gneiss; biotite-sillimanite gneiss and schist; hornblende gneiss; and granitic gneiss. In places, approximately 1.4- billion year old granite and monzogranite intrude the older units. These are the oldest rocks in the County and can be found in a small area at the northern end of the Rampart Range. The youngest, and most wide spread, of the Precambrian rocks found in the Douglas County are the approximately 1.1 billion-year-old granitic intrusives of the Pikes Peak batholith which underlie the remainder of the Rampart Range.

These crystalline rocks can be highly fractured and faulted, although distinguishing fractures from faults without marker units can be difficult. Another characteristic of the Pikes Peak Granite is its tendency to deeply weather to form grus, a granular material resembling gravel that can be quite deep in places. Both fracturing and

grusification can improve water-bearing characteristics of this otherwise very impermeable rock.

PALEOZOIC SEDIMENTARY UNITS

Paleozoic sedimentary rocks underlie several areas of the County. These units can be subdivided into two groups based on geologic history and geographic location. These two groups also define the general hydrostratigraphic units described herein.

CAMBRIAN THROUGH MISSISSIPPIAN SEDIMENTARY UNITS

Cambrian through Mississippian sedimentary rocks occur in three non-contiguous areas of Douglas County (Plate 1). Two are found along the Rampart Range fault and the third is within the Rampart Range in a small fault-bound block in the Trout Creek Valley. The units are considered collectively in this discussion and on the map because of their limited extent. Although their use as aquifers in the County is very limited, these units are recognized as aquifers elsewhere in the state (Topper and others, 2003). The units include the Cambrian Sawatch Quartzite, Ordovician Manitou Formation, and Mississippian Leadville Limestone. The basal Sawatch Quartzite overlies the Precambrian igneous and metamorphic rocks separated by a nonconformity representing a time gap of nearly 600 Ma. Thickness of the combined units varies from approximately 90 feet near Perry Park to almost 260 feet near Trout Creek.

PENNSYLVANIAN AND PERMIAN SEDIMENTARY UNITS ASSOCIATED WITH THE ANCESTRAL ROCKY MOUNTAINS

Tectonic activity from Late Mississippian through Permian resulted in the development of a series of uplifts and downwarps throughout the region. Erosion removed the older Paleozoic sedimentary rocks from the Precambrian metamorphic and igneous cores of uplifts commonly referred to as the Ancestral Rocky Mountains, or which Nesse (2006) has proposed calling "*Anasazi uplifts*". Concurrently, clastic sediments, carbonates, and evaporite deposits accumulated in the subsiding basins (De Voto, 1971; Ruleman and others, 2011; Houck and others, 2012; Kirkham and others, 2012). Orientations of these ancient uplifts and basins are not well constrained, but are approximately defined by the distribution of the basin sediments that have survived subsequent tectonic disruption (Kluth, 1997 and 2007).

Douglas County Stratigraphic Column, Cretaceous through Quaternary Units

AGE	GEOLOGIC UNIT (Thickness in feet)	LITHOLOGY	MAP IDENT.	EXTENT	ENERGY RESOURCE	AQUIFER
QUATERNARY	Holocene Alluvium (up to 20)	gravel, sand, and clay connected to modern rivers	Qa	widespread in valleys and along rivers and tributaries	limited sand and gravel	Alluvial Aquifer
	Pleistocene Alluvium (up to 120)	gravel, sand, clay, eolian sand and silt on uplands	Qu			Quat. units undif.
Oligocene ? Eocene	Castle Rock Conglomerate. (up to 135)	pebble to boulder arkosic conglomerate	Tu	widespread cap-rock in east-central part of the County	dimension stone	Post-Laramide Units
	Wall Mountain Tuff (up to 50)	rhyolitic ash-flow tuff		isolated cap-rock in east-central part of the County	dimension stone	
	Larkspur Conglomerate (up to 40)	pebble to boulder arkosic/poly lithic conglomerate		isolated to east-central part of the County	limited gravel	
	D2 Dawson Arkose (up to 800)	massive arkosic sandstone and pebble conglomerate with occasional olive mudstone (variegated claystone at bottom)	Tda	widespread across east side of the County	uranium potential fire clay	Dawson Arkose Upper Dawson Aquifer
	Upper Mudstone (up to 150)		KTd1m			confining unit
PALEOCENE	Upper Fan (up to 400)		KTd1u			D1 Upper Fan Lower Dawson Aquifer
	Denver Formation (up to 1,900)	siltstone and dark colored mudstone with lenses of arkosic sandstone in places sandstone lenses coalesce in more continuous fan systems	KTd	exposed at the surface in central part of the County widespread beneath the surface across the eastern half of the County		confining unit D1 Middle Unit Denver Aquifer
	Lower Fan (Wildcat Mtn Fan) (up to 450)		KTd1l			confining unit D1 Lower Fan Arapahoe Aquifer
	Arapahoe Congl. (up to 50)	pebble-cobble poly lithic conglomerate				
	Laramie Formation (350 - 400)	shale, sandstone, and coal	Kl	exposed at the surface in places along the Hogback	coal, methane, and uranium potential	confining unit
UPPER CRETACEOUS	Fox Hills Sandstone (200 - 250)	sandstone	Kfh	widespread beneath the surface across the eastern half of the County		Laramie-Fox Hills Aquifer
	Pierre Shale (4,200-5,300)	shale, sandstone, bentonitic layers	Kp			Cretaceous marine shale unit
	Niobrara Formation (400-550)	calcareous shale and limestone	Kn	exposed at surface along the Hogback	oil and gas potential	generally a confining unit, sand beds and fractures can be local water sources
	Benton Group (~250)	shale, limestone, and bentonite beds	Kb			
	Dakota Group (250-300)	sandstone, pebble conglomerate, and shale	Kd	exposed at surface along the Hogback	oil and gas potential	Dakota Aquifer
LOWER CRET.						

FIGURE 2A. DOUGLAS COUNTY STRATIGRAPHIC COLUMN SHOWING UNITS ADDRESSED IN THIS STUDY, QUATERNARY THROUGH LOWER CRETACEOUS UNITS.

Douglas County Stratigraphic Column, Precambrian through Jurassic Units

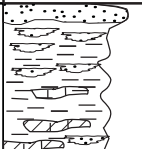




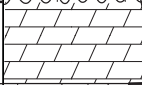


AGE	GEOLOGIC UNIT (Thickness in feet)	LITHOLOGY	MAP IDENT.	EXTENT	ENERGY RESOURCE	AQUIFER
JURASSIC	Morrison- Ralston Creek Formations (up to 610)	 mudstone and siltstone with sandstone, limestone, conglomerate, and gypsum	Jm	isolated along Hogback	potential uranium	Triassic-Jurassic-units sand beds and fractures can be local sources of water
TRIASSIC	Lykins Formation (130–140)	 shale, siltstone, gypsum, dolostone	Tl			
PERMIAN	Lyons Sandstone (app. 300)	 sandstone and minor conglomerate		isolated along Hogback		Lyons-Fountain Aquifer
PENNSYLVANIAN	Fountain Formation (up to 2,000)	 sandstone, siltstone, shale, conglomerate,	PPu	isolated along Hogback		lower part is variable, with porous zones interbedded with confining shales
MISSISSIPPIAN	Williams Canyon Member Leadville Limestone (app. 50)	 dolomite and mudstone with beds of quartz sandstone		isolated along Hogback		Older Paleozoic unit
ORDOVICIAN	Manitou Formation (app. 130)	 limestone, dolomite and shale	CMu	isolated along Hogback		solution channels, cavities, and fractures can yield water
CAMBRIAN	Sawatch Sandstone (app. 60)	 sandstone		isolated along Hogback		
PRECAMBRIAN	Paleoproterozoic to Mesoproterozoic Intrusive and Metamorphic Rocks	 igneous granitic plutons of the Pikes Peak Batholith and other intrusive bodies with metamorphic gneiss of varying composition	Yi Xi Xm	widespread over the west side of the County	uranium potential	Fractured crystalline rock aquifer igneous rocks metamorphic rocks

FIGURE 2B. DOUGLAS COUNTY STRATIGRAPHIC COLUMN SHOWING UNITS ADDRESSED IN THIS STUDY, JURASSIC THROUGH PRECAMBRIAN UNITS.

On the east flank of the Front Range Uplift the clastic sediments derived from erosion of the Paleozoic uplift make up the Fountain Formation. This unit consists of thin to thick beds of arkosic sandstone interbedded with siltstone and shale exposed along the Rampart Range fault zone at Roxborough Park and Perry Park. Grain size in the arkose ranges from fine to coarse gravel. Thickness may exceed 2,000 feet, based on surface outcrop exposure (Morgan and others, 2004). Authors often include the underlying Glen Eyrie interbedded claystones and sandstones with the Fountain Formation (Morgan and others, 2004).

The upper part of the Fountain Formation is transitional to the Lyons Sandstone. The Lyons Sandstone is generally finer grained and less stratified with siltstone and shale containing mostly frosted grains of quartz (Morgan and others, 2004), indicating a wind-blown origin. The unit contains minor isolated beds of conglomerate. Thickness reaches 300 feet in the dipping hogbacks of Perry Park.

MESOZOIC SEDIMENTARY UNITS

Triassic and Jurassic sedimentary units mark a period of tectonic quiescence for the region prior to encroachment of the Cretaceous Interior Seaway. Sediments deposited during this time include the Lykins, Ralston Creek, and Morrison Formations and are exposed along the Rampart Range fault zone just east of exposures of Lyons Sandstone in the Roxborough Park and Perry Park areas (Scott, 1963b; Morgan and others, 2004). The Lykins Formation consists of sandy siltstone and shale with layers of anhydrite and carbonate, suggesting deposition in a shallow, hypersaline, marine environment. The Ralston Creek Formation consists of thin-bedded sandstone, siltstone and shale with massive beds of gypsum. The Morrison Formation consists of interbedded shale, sandstone, claystone, and limestone. Total thickness of the three units can exceed 600 feet.

Encroachment of the Cretaceous Interior Seaway (Seaway) is marked by deposition of the Dakota Group. Included in this unit are the Purgatoire Formation, which consists of a basal Lytle Sandstone Member and overlying Glencairn Shale Member, and the South Platte Sandstone (Ruleman and others, 2011). The upper Kassler Sandstone is also commonly called the Dakota Sandstone (Scott, 1963b; Morgan and others, 2004). It includes thin to massive beds of sandstone and pebble conglomerate interbedded with siltstone, shale, and lignitic shale. The units represent a coastal environment alternating between

shoreline, fluvial channel, and overbank settings. Total thickness reaches 300 feet.

Volumetrically, marine shale dominates this group of sediments above the Dakota Group. These units, collectively referred to as the Cretaceous Seaway units herein, accumulated over the 30 to 40 Ma period during which the Interior Seaway occupied the region. It includes, from bottom up: shale and limestone of the Benton Group; limestone and calcareous shale of the Niobrara Formation; and interbedded shale, bentonite, and minor sandstone of the Pierre Shale. Total thickness is quite variable from over 5,500 feet at the basin edge to at least 6,800 feet within the basin (Scott, 1963b; Morgan and others, 2004; Ruleman and others, 2011).

The Pierre Shale grades upward into the Fox Hills Sandstone. The Fox Hills Sandstone was deposited in near-shore and beach environments of the retreating Interior Seaway (Weimer and Tillman, 1980). Eastward retreat of the Seaway caused individual overlapping sandstone bodies to climb up-section and become progressively younger to the east (Dechesne and others, 2011). The Fox Hills Sandstone can be up to 250 feet thick, and combined with sands of the Lower Laramie Formation, the entire sequence can be nearly 400 feet thick.

The Fox Hills Sandstone is in turn overlain by, and interfingers with, non-marine Laramie Formation. This upper unit of the group consists of overbank shale interbedded with lenticular beds of sandstone deposited on a low-relief coastal plain following the retreat of the Interior Seaway. This formation includes coal beds near its base that were exploited in the 19th and early 20th centuries (Emmons and others, 1896; Kirkham and Ladwig, 1979). Fine-grained overbank mudstone deposits predominate toward the top, whereas the abundance of fluvial channel sandstones diminishes.

CRETACEOUS AND TERTIARY LARAMIDE SEDIMENTARY UNITS

Late Cretaceous, Paleogene, and Eocene sediments record the evolution of the Laramide uplift throughout the Rocky Mountain region (Chapin and Cather, 1983; Reynolds, 1997). During this period of uplift, which lasted from approximately 70 Ma to 50 Ma (Dechesne and others, 2011), a series of Precambrian basement-core blocks rose to the surface while basins subsided between and flanked the blocks. Clastic sediments shed off of the rising blocks accumulated in the intervening basins. Igneous activity

concurrently contributed volcanic material to the sedimentary basin fill. Geometry and style of uplift may have evolved and changed during this prolonged period of uplift and details are still being unraveled through surface and subsurface mapping over the past 100 years and continuing today.

An unconformity separates the syn-orogenic Denver Basin Group from the underlying Laramie Formation (Raynolds, 2002; Thorson, 2011). This unconformity represents a change in the regional geography from a low-relief coastal plain to a more dynamic fluvial plain dominated by the Front Range immediately to the west. The Denver Basin Group records unroofing of the rising Front Range uplift as the basin developed. It, in turn, can be subdivided into two main sequences (Raynolds, 2002), the D1 sequence, which consists of Late Cretaceous to mid-Paleocene sediments, and the D2 sequence, which consists primarily of Eocene sediments.

The D1 sequence of the Denver Basin Group, herein referred to as the D1 sequence, includes sediments traditionally mapped as the Arapahoe Formation, portions of the Dawson Arkose, and portions of the Denver Formation. A widespread veneer of coarse sand and gravel with varied clast lithology, called the Arapahoe Conglomerate, occurs at the base of the D1 sequence. This unit consists of pebbles and cobbles derived from the eroding Paleozoic and Early Mesozoic sedimentary strata at the onset of mountain formation. Clast lithology includes granite, chert, metamorphic rocks, fossil wood, some volcanic pebbles, and abundant quartzite. These gravel beds accumulated in a widespread low relief fan across the basin, filling in lows in preexisting topography. This basal conglomerate is up to 16 feet thick near the mountains and thins to less than three feet near the distal eastern and southern edges of the basin. Because of its limited thickness and exposure, the Arapahoe Conglomerate is normally not a mappable unit at common map scales, but is included in overlying units (for example, Thorson, 2011).

In most areas, the Arapahoe Conglomerate is directly overlain by arkosic fluvial strata deposited as erosion and unroofing of the Laramide Rocky Mountains exposed Precambrian crystalline rocks. Broad fluvial, distributary fans formed at the western margin of the basin that can be mapped in the subsurface and in places are exposed as resistant sandstone outcrops. Examples of these fans are the Wildcat Mountain fan (Raynolds and Johnson, 2003) and the Pikeview Formation fan (Thorson, 2011; Thorson and Himmelreich, 2002). Sediments in the D1 sequence

range from coarse proximal sandstone beds, to shale beds, interbedded with beds of lignite on the distal eastern side of the basin (Kirkham and Ladwig, 1979; Nichols, 1999). In places the clast compositions are andesitic, suggesting that volcanic edifices crowned the Front Range. Superimposed arkosic strata record the removal of these volcanic edifices and the erosion of the underlying Precambrian source materials. The D1 sequence is interpreted to have formed between about 68 to about 64 Ma (Raynolds and Johnson, 2003; Nichols and Fleming, 2002) spanning the Cretaceous/Tertiary, or K-T, boundary.

During D1 sequence sedimentation, progressive angular unconformities developed at the active western basin margin as the mountains were uplifting and the basin was actively deepening. Uplift at the range front rotated the just-deposited beds which were in turn truncated by erosion to be unconformably overlain by the next series of coarse-grained fan deposits. This relationship is best exposed between Monument and Colorado Springs (Kluth and Nelson, 1988). It may be present within Douglas County, but exposures of the interval where it would be found are poor, obscuring subtle stratigraphic features that would reveal the complex relationship.

The D2 sequence of the Denver Basin Group, herein referred to as the D2 sequence, unconformably overlies the D1 sequence (Raynolds, 2002). Thickness patterns and paleocurrent indicators suggest provenance from the southwestern portion of the basin in the Pikes Peak area. The occurrence of amazonite within this unit corroborates this, as the principal source for amazonite is from pegmatites in the Pikes Peak batholith.

In places, the unconformity at the base of the D2 sequence may represent a hiatus in sedimentation of approximately eight million years between 64 and 56 Ma. Chronology and sedimentation patterns during this interval of the late Paleocene are still not well constrained. However, CGS mappers have identified organic-rich beds near the western part of the basin with recovered palynology dates within this time frame (Thorson, 2011). This suggests that the basin may have had local accommodation space near the mountains to preserve these thin veneers of sediment.

An aggradational paleosol interval developed at the beginning of the Eocene that serves as a regional marker at the base of the D2 sequence within much of the basin. This interval is of variable thickness, sometimes exceeding 20 feet, and contains deep-red, yellow, and purple lateritic horizons (Soister and Tschudy, 1978; Farnham and Kraus, 2002). Fluvial strata above the paleosol interval are arkosic

and tend to be coarser grained than strata below, indicating a renewed pulse of sediment entering the basin after the hiatus. On the western side of the basin the interval of deeply weathered paleosols is harder to recognize than in other parts of the basin. The coarse-grained sediments near the mountains were continuously uplifted with the mountain front and were more prone to form red, oxidizing paleosols. Other, not as well developed, paleosols have been found at multiple stratigraphic depths in this region and it is hard to distinguish local paleosols from the regionally recognized paleosol interval.

In Douglas County the D1 sequence can be divided into four main members (Figure 2a) consisting of two well-developed fan systems separated by an interval that is mudstone-dominated, particularly to the east. The lower fan includes the basal Arapahoe Conglomerate and Wildcat Mountain fan complex corresponding to the Arapahoe Aquifer (Raynolds and Johnson, 2003). The middle mudstone-dominated interval is the most widely exposed unit at the surface and has been mapped as the Denver Formation (Thorson, 2011) and corresponds to the Denver Aquifer. The upper fan corresponds to the Lower Dawson Aquifer while the fourth unit is a mudstone layer above the upper fan system. Collectively, the entire D1 sequence can exceed 2,000 feet in thickness (Dechesne and others, 2011). The D2 sequence consists of the Dawson Arkose and corresponds to the Upper Dawson Aquifer. This unit reaches 800 feet in thickness.

POST-LARAMIDE VOLCANIC AND SEDIMENTARY UNITS

The region continued to be modified by tectonism after the primary Laramide uplift event; however, the style of deformation changed. Although it is difficult to find material to date the units above the Denver Basin Group, stratigraphic relationships indicate that there was a period of erosion following deposition of the Dawson Arkose (Thorson, 2011). The Larkspur Conglomerate was deposited across this erosion surface and represents a high energy fluvial deposit. Clasts of quartzite believed to be derived from Coal Creek near Boulder suggest a northwesterly source. Next in the sequence is the late Eocene Wall Mountain Tuff, a volcanic ash layer which blanketed a large part of the region, sourced from a postulated caldera northwest of Salida (Chapin and Lowell, 1979). The Wall Mountain Tuff has been dated at 36.7 Ma (Epis and Chapin, 1974, McIntosh and Chapin, 1994). Small remnants cap many buttes in central Douglas County and have been

utilized for attractive dimension stone since the 19th century. Emplacement of the Wall Mountain Tuff was soon followed by deposition of the Castle Rock Conglomerate. This unit was also deposited by very high energy streams that eroded deep channels in the Wall Mountain Tuff as evidenced by very large boulders of tuff “floating” in beds of gravel in the Castle Rock Conglomerate.

QUATERNARY DEPOSITS

Quaternary deposits include extensive alluvium associated with modern stream systems, gravel deposits from older stream systems long abandoned, and wind deposits of sand and finer-grained loess. Evidence has not been documented that any areas in the higher parts of the Rampart Range were glaciated. However, alluvial deposits record episodes of deposition followed by erosion that correspond to periods of glaciation followed by de-glaciation elsewhere in the region (Scott, 1963a). Wind-deposited sand and loess are interpreted to reflect climatic conditions during periods of glaciation (Madole and others, 2005).

The manner in which these many Quaternary deposits have been mapped has varied among geologists over time. Classification schemes and nomenclature as well as interpretations of relationships among alluvial deposits have changed over time. Some of the earliest efforts at mapping and understanding the relationships of various alluvial deposits were undertaken by Scott (1963a) in the Kassler Quadrangle at the northwestern corner of the County. Scott recognized a series of terraces capped with stream-deposited alluvium along river valleys that reflected gradual down-cutting of the river courses in the landscape. Terrace deposits become progressively younger as they drop down to the modern level. These include from the oldest: Rocky Flats, Verdos, Slocum, Louviers, Broadway, and Piney Creek. Recent mapping efforts do not always follow this naming scheme; however, the concept of older deposits covering terraces higher above the modern level remains the same.

Generally the older, higher, deposits mantle bedrock surfaces and are not necessarily connected with more recent alluvium (Scott, 1963a). Scott indicated that only Slocum and younger seemed to fill the alluvial channel occupied by the modern streams. Because of this relationship, the Quaternary alluvium shown in the general geologic map, Plate 1, is drawn to include Slocum, or equivalent, and younger. Older alluvium, such as Rocky Flats and Verdos, have been excluded from the alluvium layer and are instead included in the undifferentiated

Quaternary deposits along with eolian and landslide deposits.

Quaternary deposits consist of unconsolidated sand and gravel with basal layers of cobbles and boulders in places. Layers of clay and silt deposited in low velocity or standing water can be present anywhere in a deposit of alluvium. Most terraces have alluvium capped with well-developed soils composed of loam, loess, and rich organic material.

STRUCTURAL GEOLOGY

The structural setting of Douglas County is quite complex owing to its long and varied evolution. Primary features consist of the uplifted Front Range on the west and the downwarped Denver Basin to the east. The Rampart Range fault zone is a third feature that separates the two. Each of these features in turn is composed of structural features of multiple scales that add complexity to the regional setting. **Figure 3** is a map showing many of the structural features mapped in Douglas County and the surrounding area. **Plate 2** is a cross section that illustrates the relationship of the uplift and downwarp across the fault zone.

RAMPART RANGE FAULT ZONE

The Rampart Range fault zone is a north to northwest-trending linear feature often described as a faulted monocline. This description oversimplifies its complexity as distinctly different styles of deformation mark alternating segments along its extent. Two segments are indeed monoclines and consist of eastward-dipping Paleozoic and Mesozoic sedimentary units with a general northwesterly structural orientation. These are denoted as hogback belt segments in **Figure 3**. One, at the north end of the fault zone in the County, extends southward from Roxborough Park to Wildcat Mountain. The other passes through Perry Park midway along the fault zone. Resistant beds of the Fountain Formation; Lyons Sandstone; Dakota Group; and occasionally the Fox Hills Sandstone and Laramie Formation, stand out as scenic hogbacks in these areas. Locally, Cambrian sediments or the Pennsylvanian Fountain Formation unconformably overly Precambrian crystalline rocks with little evidence of faulting.

In contrast, other segments interrupt the hogback belt that consist of a dominant fault, or multiple faults, which

abruptly place older crystalline rocks against Mesozoic sedimentary units. These segments display a more northerly orientation than the hogback belt. One of these segments extends southward from Wildcat Mountain to Jackson Creek at the north edge of Perry Park. The second continues from the south edge of Perry Park to Palmer Lake (**Figure 3**).

There can be multiple splays of the fault zone, particularly where it deviates from its overall northwest trend. Where this occurs, the zone can reach over five miles in width. A good example is in the area of Perry Park where the zones splits into the Rampart Range-Jarre Canyon fault zone, Perry Park splay, and West Plum Creek splay (Morgan and others, 2004). Total vertical displacement across this fault zone may reach 15,000 feet (Hemborg, 1996; Temple and others, 2008). Sterne (2006) argues that the zone consists of a series of stacked “triangle” zones that include deep thrusts combined with complimentary back thrusts.

FRONT RANGE UPLIFT

The Front Range uplift is a regional feature which brings Precambrian crystalline igneous and metamorphic rocks that formed at great depths under pressure and high temperature to the surface. This uplift forms the rugged Rampart Range in western Douglas County (**Figure 3**). Although it appears as a singular block of rock resistant to erosion, geologic mapping within the range has identified many faults of varying displacement and orientation. Density of faults shown in the map reflects the scale of mapping effort and suggests that many faults have yet to be identified. Because of the great age of the crystalline igneous and metamorphic rocks in this area, there have been multiple stress regimes across the area leading to multiple styles and orientations of deformation. With a lack of younger strata and marker beds, it is often difficult to determine the sense of displacement. Temple and others (2008) identified several north-south high-angle faults east of Trout Creek that indicate general up-to-the-east movement. East of the Rampart Range, the faults tend to show down-to-the-east displacement. Because of fracturing and possible enhanced weathering in fault zones, they are more susceptible to erosion. For this reason many streams and draws follow fault traces.

Faulting within Rampart Range in the vicinity of Trout Creek preserves a remnant of Paleozoic sedimentary rocks in an area dominated by igneous rocks of the Pikes Peak Batholith (Interior fault block in **Figure 3**). Displacement along the Ute Pass Fault, with the east side down, drops

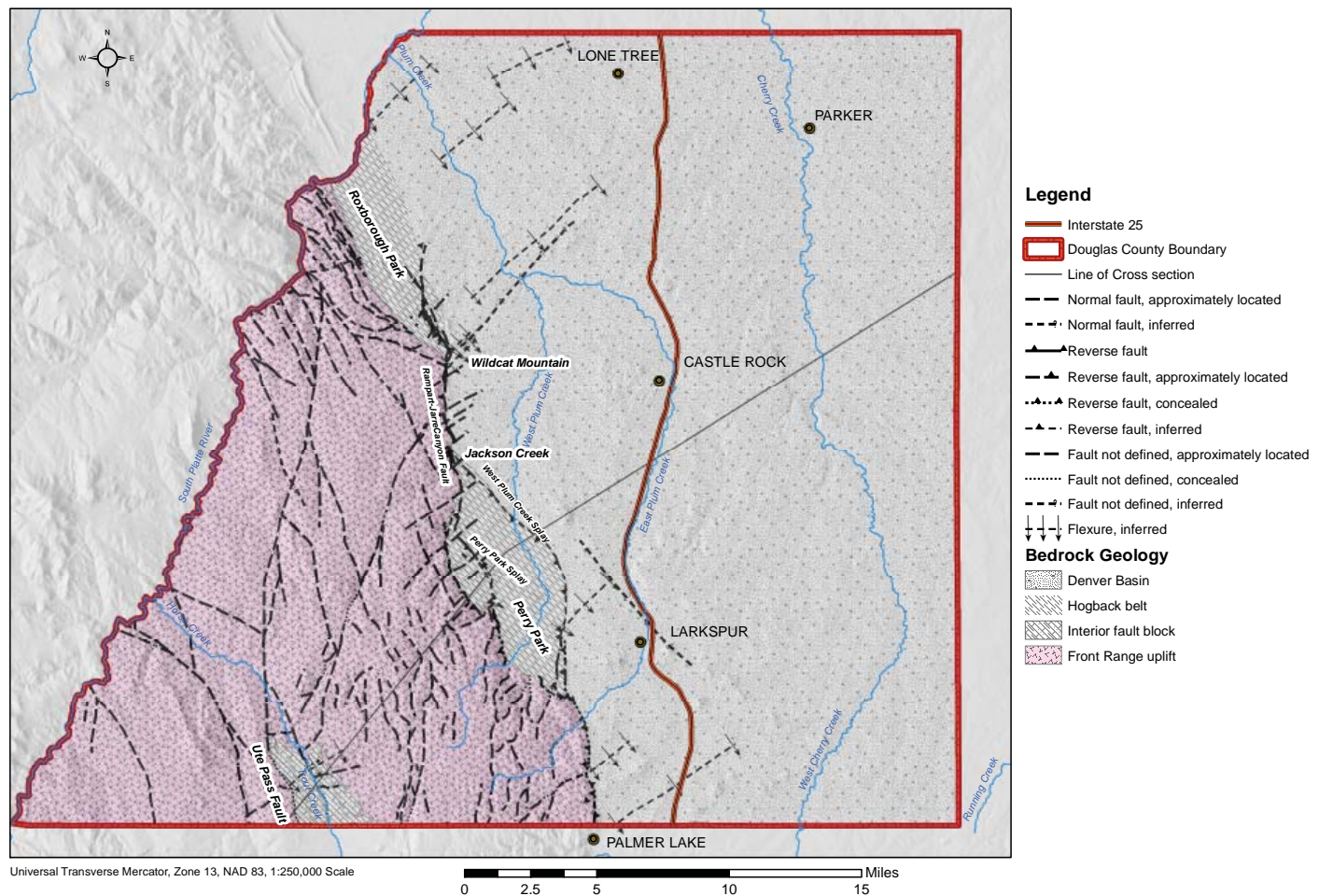


FIGURE 3. STRUCTURAL FEATURES OF DOUGLAS COUNTY. The Front Range uplift and Denver Basin downwarp, along with the Rampart Range Fault zone that separates the two, define the structural setting of Douglas County. Many other faults have also been identified through detailed mapping efforts. Better rock exposures in the crystalline core of the Front Range uplift allow better identification of faults in the field. Faults are less likely to be observed in the field within the Denver Basin where there is more Quaternary cover and the bedrock is poorly consolidated. Deep concealed faults may express themselves as subtle flexures evident in structure maps of bedrock strata.

the sedimentary units in a small west-dipping half-graben. These sediments, which formerly blanketed the entire region, have been entirely stripped off of the range by erosion during uplift except within the down-faulted block.

DENVER BASIN

The Denver Basin, as defined by the extent of Upper Cretaceous and Tertiary synorogenic Denver Basin Group sedimentary deposits, can be generally described as an asymmetric depression with its steepest limb along its west edge, next to the Rampart Range fault zone. This places the northwest-trending axis on the west side of the basin and near the east edge of Douglas County (Figure 3). The Mesozoic and Cenozoic strata within the basin east of the axis exhibit gentle westerly dips, mostly less than 5 degrees. West of the axis, strata dip to the east, with angles increasing closer to the Rampart Range fault zone. In places, dips reach 90 degrees, or the strata can even be overturned.

Other subtle deformation of strata within the basin in addition to the regional downwarp is evident. Van Slyke (1996) has mapped a number of northeast-trending faults that offset main bounding faults of the Rampart Range fault zone. Many of these small faults extend some distance into the basin. One of these faults may extend from just south of Wildcat Mountain, over seven miles into the basin to Sedalia and on to Cherokee Ranch (Van Slyke, 1996; Morgan and others, 2005). Detailed correlation of geophysical logs and contouring of subsurface elevation data reveal that similar trending deformation extends well into the basin away from the Rampart Range fault zone. Basin-wide structure maps published in the Denver Basin Rules (CDWR, 1985) show an orthogonal pattern with cross-cutting northwest and northeast linear trends. Many of these features may be gentle flexures in the Mesozoic and Cenozoic sedimentary strata above deep basement faults. These are shown as inferred flexures in Figure 3. Two notable flexures cross Douglas County including the one that parallels the fault mapped by Van Slyke (1996) and Morgan and others (2005) near Sedalia. A second prominent flexure extends northeast from the Rampart Range fault zone beneath Palmer Divide. These inferred structures appear as subtle folds of low magnitude poorly expressed at the surface. Reliable structural attitude measurements are difficult to obtain in the fluvial sedimentary deposits that are often deeply weathered and modified at the surface. As subtle as these features may be, there is potential for enhanced fracturing of more brittle beds associated with the deformation. Enhanced

fracturing could locally augment permeability. In a layered system, enhancement of vertical permeability could modify fluid flow patterns that otherwise would be dominated by horizontal stratification.

OTHER STRUCTURAL FEATURES

Early Paleozoic strata occur in only two locations in Douglas County; one along Trout Creek within the Rampart Range, and at the other near Perry Park along the Rampart Range fault zone. During Permian and Pennsylvanian uplift of the Ancestral Rock Mountains older strata were eroded from the uplifted ranges. It is generally thought that this part of the modern Front Range was also an uplifted range during this earlier period of mountain building and erosion (Kluth, 1997). The presence of these two isolated pockets of older Paleozoic strata would suggest that there were areas of the earlier uplift that were not completely stripped of their older sedimentary cover. The structural geometry that preserved these areas is not well understood. However, as already described, Paleozoic strata are preserved in the half-graben bounded by the Ute Pass Fault along Trout Creek. This suggests that the Ute Pass Fault, or other cross-cutting structural elements, were active in this area during structural evolution of the Ancestral Rocky Mountains.

GROUNDWATER IN DOUGLAS COUNTY



This section describes the various aquifers present in Douglas County following the framework outlined in the previous general geologic description. With the intent to provide a general overview of groundwater resources on a county-wide basis, the descriptions are general. For some aquifers, data are sparse, while for others very detailed descriptions are available elsewhere in the literature. References are provided for the latter.

Discussion of groundwater resources in the County is organized by hydrogeologic units which may span several geologic units, or may be subdivisions of heterogeneous geologic units. Aquifers and hydrogeologic units in the County can be grouped into the following categories:

1. Fractured crystalline rock aquifers
 - Precambrian igneous and metamorphic rocks
2. Sedimentary bedrock aquifers and confining units
 - Paleozoic hydrogeologic units
 - Triassic-Jurassic unit
 - Dakota Group Aquifer
 - Cretaceous marine shale unit
 - Laramie-Fox Hills Aquifer
 - Denver Basin Group hydrogeologic units
 - Post-Laramide units
3. Alluvial Aquifer

Plates 3 through 20 show the extent of each unit based on surface outcrop patterns and projections into the subsurface. Projections into the subsurface use surface measured dip angles subsurface data where available. Maps of the bedrock units include projected intersections with alluvium to illustrate potential connection with surface water systems. The maps also include wells estimated to be completed in each unit. These maps were generated using ArcGIS (ESRI, 2014)

Water well distribution and groundwater resource utilization by hydrogeologic unit in the County was determined by querying the well permit database of the Colorado Division of Water Resources (DWR), accessed February 2013. Useful data included permit number, receipt number, well location, depth, screen interval, and permitted use. Duplicates in the database were selected out and only wells having a current status of “Well Constructed” were included in the analysis. Many wells do not have specific aquifer designation in the database, and for these, well location and depth relative to surficial geology were used to create initial estimates of hydrogeologic completion intervals for each well. Lithologic logs describing materials encountered during drilling were examined for many wells near the margins of hydrogeologic units and for deeper wells away from margins to verify completions identified by the initial estimate. This is an imprecise method of assigning aquifer designations to individual wells, but suits the scope of this study in identifying utilization of the groundwater resources in the area. Many wells in the Denver Basin have “All Unnamed” noted as aquifer in the database. Because of the complications of aquifer designation in the Denver Basin, these wells remain with the DWR “All Unnamed” designation in the database for these maps.

Location accuracy in the DWR database is also a limiting factor for accuracy of the aquifer determinations presented in these maps. Many well locations have only been recorded in the database by quarter-quarter section reference. Others are located using manual measurements off of topographic maps. Therefore, aquifer designations and well statistics by aquifer in this study are only estimates using available data. Any determination on a site-specific basis will require better location determination.

FRACTURED CRYSTALLINE ROCK AQUIFERS

Crystalline rock aquifers in Douglas County can be subdivided into two general hydrogeologic units on the basis of rock type and internal fabric: igneous and metamorphic rocks. Both types are Precambrian in age and are found in the Rampart Range (Plate 3).

PRECAMBRIAN IGNEOUS ROCKS

Precambrian igneous rocks form the most widespread fractured crystalline rock aquifer covering the southern two-thirds of the length of the Rampart Range. It consists of Pikes Peak granite with minor pegmatite bodies. Detailed mapping subdivides the granite into different phases based on slight mineralogical and textural differences (Temple and others, 2008; Thorson and others, 2008; Ruleman and others, 2011); however, in considering the rock as an aquifer, the sub-units are treated as a single unit in these maps. In the Rampart Range, Pikes Peak granite is widespread and forms the primary aquifer unless alluvium is present above it, which is very rare. There is essentially no primary porosity in these rocks with secondary fractures storing and transmitting groundwater. Locally, the granite can be deeply weathered into grus, which can enhance secondary porosity and permeability. Where grusification has been very advanced, the unit can be indistinguishable from local alluvium.

There is no limit to depth other than practical drilling depths. Wells are typically drilled to a depth that intercepts enough water-bearing fractures to supply a household. Aquifer parameters in fractured crystalline bedrock aquifers can be quite variable and depend on fracture density and fracture apertures.

GROUNDWATER UTILIZATION

Based on location information, 428 wells are estimated to be completed in the Precambrian igneous rocks. Of these, about 96 percent are permitted for domestic use or household use only, two percent are used for commercial uses, and the remaining used for other purposes such as irrigation. Reported well depths range from 2 to 1,200 feet with water levels ranging between 1 to 780 feet below ground surface (fbgs). Reported production rates range from 0.05 to 50 gallons per minute (gpm).

PRECAMBRIAN METAMORPHIC

ROCKS

Precambrian metamorphic rocks form a fractured crystalline rock aquifer in the northern end of the Rampart Range. This unit consists of biotite gneiss with minor inliers of hornblende-plagioclase gneiss and biotite-sillimanite gneiss. These sub-units are treated as a single unit in these maps because their physical properties are very similar. Metamorphic rocks differ from igneous in having a strong internal fabric, or foliation. Depending on mineralogical content, this can affect fracture intensity and orientation which, in turn, can affect hydrologic properties (Bossong and others, 2003). In the northern end of the Rampart Range, it forms the primary aquifer unless alluvium is present above it, which is very rare.

As with the igneous rocks in the rest of the range, there is essentially no primary porosity in these rocks with secondary fractures storing and transmitting groundwater. Aquifer parameters in fractured crystalline bedrock aquifers can be quite variable and depend on fracture density and fracture apertures. Weathering can also affect hydrologic properties of metamorphic rocks; however, not as significantly as grusification of granite. There is no limit to depth other than practical drilling depths. Wells are typically drilled to a depth that intercepts enough water-bearing fractures to supply a household.

GROUNDWATER UTILIZATION

Based on location information, 37 wells are estimated to be completed in Precambrian metamorphic rocks. All of these wells are permitted for domestic use or household use only. Where reported, depths range from 6 to 610 feet with water levels ranging between 5 and 269 fbgs. Reported production rates range from 0.5 to 36 gpm.

GROUNDWATER FLOW IN THE CRYSTALLINE ROCK AQUIFERS

The distribution of wells with reliable water level data is very limited for this unit. However, groundwater flow in the igneous and metamorphic rocks tends to follow topography from higher to lower elevations. Recharge is from direct infiltration of precipitation, particularly snowmelt in winter and spring months. Discharge is to streams that act as drains. Fracture systems and faults can impart flow directions that do not always follow topographic gradients. Some groundwater flow may leave the upland crystalline aquifer into the sedimentary aquifers along the Denver Basin edge although it is difficult to estimate the volume of outflow across the complex

bounding fault zone (Bossong and others, 2003). Fault zones often enhance porosity and permeability considerably and can be the reason for wells with anomalously high yields.

Bossong and others (2003) and CDM (2010) present a concept of groundwater flow and storage in crystalline bedrock aquifers that is useful for understanding groundwater resource potential and limitations. In this concept, recharge, primarily from precipitation passes into near-surface soils where most is taken up by evapotranspiration. What is not lost to evapotranspiration can take one of several paths. Most enters a zone of shallow groundwater interflow that feeds directly to nearby streams. Some enters a deeper zone of baseflow that maintains surface water baseflow of regional streams and rivers. A small portion may also be available to recharge a conceptual, deep groundwater reservoir. Interflow is very temporary and follows significant precipitation events and snowmelt. Baseflow can be seen as continuing through the dry seasons and maintains minimum baseflow conditions of the rivers. The deep groundwater reservoir has potential to serve as a reliable source of water on a limited basis.

SEDIMENTARY BEDROCK AQUIFERS AND CONFINING UNITS

For the purpose of this study, sedimentary bedrock aquifers and confining units are subdivided into seven general hydrogeologic units on the basis of geologic age and similar tectonic setting. Several classifications include sub-units, as described elsewhere;

- a. Older Paleozoic unit
- b. Lyons-Fountain aquifer
- c. Triassic-Jurassic unit
- d. Dakota Group Aquifer
- e. Cretaceous marine shale unit
- f. Laramie-Fox Hills Aquifer
- g. Denver Basin Group hydrogeologic units
 - D1 lower fan (DWR Arapahoe Aquifer)
 - D1 middle unit (DWR Denver Aquifer)
 - D1 upper fan (DWR Lower Dawson Aquifer)

- Dawson Arkose (Upper Dawson Aquifer)

h. Post-Laramide units

OLDER PALEOZOIC UNIT

Because of their limited extent and utilization, Cambrian through Mississippian clastic sedimentary and carbonate formations are considered a single unit in this description. Sedimentary formations included in the older Paleozoic unit include the Sawatch Quartzite, Manitou Formation, and Leadville Limestone. This unit is present at or near the surface in three small areas in the County (Plates 4 and 5). The greatest areal extent of the older Paleozoic unit straddles Trout Creek in the southern part of the Rampart Range, which is the only area in the County where the aquifer is currently utilized. This area is a fault block where a portion of the range has been down-faulted, preserving a remnant of Paleozoic cover above Precambrian Pikes Peak granite basement. The other two areas of the unit are in the vicinity of Perry Park along the Rampart Range fault zone where there are no permitted wells in the DWR records. The units may be present at much greater depths within the Denver Basin; however, anticipated depths are so great that water quality may be unsuitable for most uses. Although distribution in Douglas County is limited, the units are considered important aquifer systems elsewhere in the state (Topper and others, 2003). Total thickness ranges from 150 to 250 feet.

GROUNDWATER FLOW

Primary porosity in the clastic sediments, which are mostly quartzite and shale, tends to be quite low and groundwater is stored and transmitted through fractures. Similarly, porosity and permeability in the carbonate units tend to be in fractures and solution channels and cavities. Water level elevations from wells in the Trout Creek area are irregular; however, all are higher than nearby surface water. This suggests that groundwater flow follows topography from higher ground to incised valleys with recharge from direct infiltration of precipitation and discharge to streams.

GROUNDWATER UTILIZATION

Based on location and reported depths, 47 wells are estimated to be completed in the older Paleozoic aquifer. All of these are permitted for domestic use or household use only. Reported depths range from 120 to 640 feet with water levels ranging between 20 and 300 fbs. Reported production rates range from 0.2 to 30 gpm.

LYONS-FOUNTAIN AQUIFER

The Lyons-Fountain aquifer (Plates 6 and 7) consists of the Fountain Formation and Lyons Sandstone. These units are a heterogeneous assemblage of sandstone, conglomerate, and shale considered as a single hydrogeologic unit herein. Locally, the Lyons Sandstone could be considered a separate aquifer; however, because it is transitional with the Fountain and is of limited extent and utilization it is included with the Fountain Formation as one aquifer. This aquifer can be found in the down-faulted interior block of the Rampart Range along Trout Creek in the southern part of the County as well as the hogback belt segments of the Rampart Range fault zone near Roxborough Park and Perry Park. Thickness is quite variable up to 2,300 feet.

GROUNDWATER FLOW

Where present, the upper part of the aquifer consists of the relatively massive and laterally continuous Lyons Sandstone. This part can be considered a relatively uniform aquifer with lateral extent limited to each of the two hogback belt segments of the Rampart Range fault zone, Roxborough at the north and Perry Park in the middle. Intergranular pore spaces form the primary porosity and permeability; however, fracturing can provide secondary permeability.

The lower part of the aquifer, or Fountain Formation, consists of many distinct fluvial sand bodies with limited lateral extent interbedded in dominantly fine-grained shale and siltstone. This part can be found in the hogback belt segments of the Rampart Range fault zone as well as the Interior fault block of the Rampart Range along Trout Creek. Intergranular pore spaces form the primary porosity and permeability; however, fracturing can provide secondary permeability. Hydraulic interconnection can be limited except where faults and fractures form pathways between individual permeable bodies.

Water level elevations from wells in the areas where the aquifer is present are irregular but are all higher than nearby surface water. This suggests that groundwater flow follows topography from higher ground to incised valleys with recharge from direct infiltration of precipitation and discharge to streams or Quaternary alluvium (Plate 7).

GROUNDWATER UTILIZATION

Based on location and reported depths, 64 wells are estimated to be completed in the Lyons-Fountain aquifer. Of these 55 percent are permitted for domestic use or household use only; eight percent for commercial, industrial,

and municipal; and 14 percent for irrigation and stock. Eleven are monitoring wells and there are three geothermal wells. Where reported, depths range from 4 to 703 feet with water levels ranging between 1 and 140 fbs. Reported production rates range from 1 to 180 gpm.

TRIASSIC-JURASSIC UNIT

This unit includes the Triassic Lykins Formation along with the Jurassic Morrison and Ralston Creek Formations. Mudstone, siltstone, and shale dominate these formations and the unit can be considered a confining unit that separates the Lyons-Fountain aquifer from the overlying Dakota Group aquifer, although they may yield water locally from porous zones or fractures (Topper and others, 2003). Total thickness ranges from 700 to 750 feet. Because of limited use as an aquifer a separate map has not been generated for this unit.

GROUNDWATER UTILIZATION

Groundwater use from this aquifer is very limited indicating that other aquifers are preferable if present at reasonable depths. Based on location and reported depths, 3 wells tap the Triassic-Jurassic unit. All are listed for domestic use and two include stock use in the permit files. Two are located in the Roxborough segment of the hogback belt and one in the Perry Park segment. Well depths are between 140 and 301 feet with water levels between 8 and 40 fbs. Reported pump rates range from 15 to 125 gpm.

DAKOTA AQUIFER

The Dakota Group includes the Lower Cretaceous Dakota Sandstone and underlying Purgatoire Formation. The units are considered together herein because of their relationship with the advance of the Cretaceous Interior Seaway. Traditionally it is recognized as the Dakota Aquifer as used herein. The units consist of sandstone and conglomerate with lenses of shale. In many parts of the State, the units are considered a major aquifer (Topper and others, 2003). The Dakota Aquifer occurs at, or near the surface in the Roxborough Park and Perry Park segments of the hogback belt (Plates 8 and 9). Total thickness is between 250 and 300 feet.

GROUNDWATER FLOW

Intergranular pore spaces form primary porosity and permeability and fracturing can enhance secondary permeability. Water level elevations from a limited set of wells completed in the Dakota Aquifer indicate

groundwater flow from recharge areas in higher exposures along the hogback outcrop. Recharge is direct infiltration of precipitation, although there may be limited inflow from older units that outcrop at higher elevations to the west. Discharge is directly to stream systems where the unit intersects Quaternary alluvium.

GROUNDWATER UTILIZATION

Based on location and reported depths, 10 wells are estimated to be completed in the Dakota Aquifer. Of these, six are permitted for domestic use and two for commercial or municipal. Two are monitoring wells. Reported depths range from 13 to 730 feet with water levels ranging between 22 and 381 fbg. Reported production rates range from 8 to 450 gpm.

CRETACEOUS MARINE SHALE UNIT

In this discussion and on the maps, the Cretaceous marine shale unit consists of the Benton Group, Niobrara Formation, and Pierre Shale. Generally impermeable shale dominates these marine sediments that are considered a confining unit. Sandstone beds, limestone beds, and fractures can yield water locally that may provide the only source of water to a given site, limited as it may be. A separate map plate has not been included because of limited use of the unit.

GROUNDWATER UTILIZATION

Even though this unit is not considered an aquifer, in many areas there may not be any other source of water available. Wells are the only option, even though a well may be drilled at great expense only to yield very little water of poor quality. Based on location, 62 wells are estimated to be completed in the Cretaceous marine shale unit, seven in the Niobrara Formation and 55 in the Pierre Shale. Of these, 70 percent are permitted for household only or domestic use; one for stock watering; and three for other uses. Fourteen are monitoring wells. Where reported, depths range from 13 to 1006 feet with water levels ranging between 10 and 690 fbg. Reported production rates range from 0.5 to 50 gpm.

LARAMIE-FOX HILLS AQUIFER

The Fox Hills Sandstone combined with basal sandstone beds within the overlying Laramie Formation form a regional aquifer. Together, the units are called the Laramie-Fox Hills Aquifer in the Denver Basin as well as South Park to the west. It is the deepest of the Denver Basin Bedrock

aquifers as recognized by Robson (1983) and designated in the Denver Basin Rules (CDWR, 1985). The aquifer underlies the entire portion of the County within the Denver Basin (Plates 10 and 11). It only appears in outcrop at the surface in a few areas of the hogback belt segments near Roxborough Park and Perry Park. Elsewhere, the aquifer surface trace is either concealed by surficial deposits or truncated by faulting so that it does not continue from the subsurface to outcrop.

The Fox Hills Sandstone consists of a series of sand bodies that overlap upward to the east. These bodies have been described as “shingles” by Dechesne and others (2011) that collectively form a relatively continuous body of sand. In this manner the unit forms the most laterally continuous aquifer in the County. Basal sands of the overlying Laramie Formation tend to display a more lenticular geometry, and therefore are not as laterally continuous as the Fox Hills Sandstone. Thickness of the Fox Hills Sandstone is quite variable depending on overlapping sand bodies, but it typically ranges between 200 and 250 feet. The Laramie sands above area also variable and can bring the total thickness up to 350 feet in places.

GROUNDWATER FLOW

Intergranular pore spaces form the primary porosity and permeability and fracturing can enhance permeability locally. Cementation in the Fox Hills can be variable, filling nearly all pore spaces in some places. Prior to development and under natural conditions, groundwater flow in the Laramie-Fox Hills Aquifer is estimated to have been generally to the north from Palmer Divide to the South Platte River north of Denver, where the aquifer subcrops the alluvial basin (Paschke, 2011). Estimated flow lines from Paschke (2011) are included in Plate 12 that show that still flows to the north, similar to predevelopment patterns in Douglas County. Recharge to the aquifer is from direct infiltration at the limited outcrop, including intersections with stream systems and Quaternary alluvium (Plate 11). The greatest recharge, however, is believed to be downward flow from overlying aquifers (Robson, 1987; Paschke, 2011). Discharge is through well pumping and outflow to the South Platte River at the north end of the Denver Basin.

GROUNDWATER UTILIZATION

DWR records indicate that an estimated 79 wells tap the Laramie-Fox Hills aquifer. Of these, 34 percent of the wells are permitted for domestic use or household use only; four percent are used for irrigation; and 49 percent

are used for industrial and commercial purposes. Seven wells are permitted for all beneficial uses and three are listed as “other”.

LARAMIE FORMATION

The upper part of the Laramie Formation consists of shale with lenticular beds of sandstone and coal. It is considered a confining unit, as designated in the Denver Basin Rules (CDWR, 1985).

DENVER BASIN GROUP HYDROGEOLOGIC UNITS

The Denver Basin Group hydrogeologic units consist of several sedimentary members that were deposited during active uplift of the Front Range mountain front immediately to the west. Sediments in this group differ from older units in that the geometry of various interbedded sandstone bodies and interbedded mudstones relate directly to proximity of the uplifted mountain front. Sediments were transported out of the rising uplift across a number of distributary fan complexes that extended out into the basin. Grain size, sand bed thickness, and ratio of sand to finer grained silt and mudstone increases near the mountain front and axis of the ancient fan complexes. The cross section (Plate 2) illustrates the complex geometry of these formations and its relationship to the range front and Rampart Range fault zone.

The following are subdivisions of the Denver Basin Group hydrogeologic units based on outcrop patterns as well as revised interpretations of geophysical logs and well to well correlations as described by Barkmann and others (2011). **Figure 4** is a type log through the Denver Basin Group delineating the units in the subsurface.

These subdivisions correspond closely to the Denver Basin Bedrock Aquifers described by Robson (1983) and designated in the Denver Basin Rules (CDWR, 1985). The corresponding aquifers are noted in the text, stratigraphic column (Figure 2), type log (Figure 4), and maps (Plates 12-17).

Stratigraphic subdivisions described herein do not always correspond directly with the Denver Basin Bedrock Aquifers as defined in the Denver Basin Rules. This arises from differences in interpretations derived in the 1980s when the Denver Basin Rules were devised using older and limited sets of data and interpretations derived in 2011 using an expanded set of data (Barkmann and others, 2011). Although the newer interpretations may more

closely describe the geologic framework, the Denver Basin Rules still apply to water rights administration. Any applications for well permits or water rights determinations must follow the Denver Basin Rules (CDWR, 1985). The revised interpretation herein provides a newer perspective when understanding groundwater flow patterns and responses to stress as the resource is developed.

Well designations in the discussion below are directly from the DWR permit file database. Many wells have non-specific aquifer designations (“GW” or “ALL UNNAMED AQUIFERS”). Only those wells with specific aquifer designations in the DWR database have been included in this discussion. Assignment of hydrogeologic unit to these non-specified wells can be done through a GIS analysis.

D1 LOWER FAN

This unit consists of the lowermost fan complex of the Denver Basin Group D1 sequence (Raynolds, 2002; Dechesne and others, 2011). It consists of units mapped at the surface as Arapahoe Conglomerate, Denver Formation, and Pulpit Rock Formation south of Palmer Divide (Thorson, 2011). In Douglas County the unit includes the Wildcat Mountain fan of Raynolds and Johnson (2003). The unit generally corresponds to the Arapahoe Aquifer and underlies all of the County within the Denver Basin (Plates 12 and 13). It appears in outcrop at the surface in a few areas along the Rampart Range fault zone from Roxborough Park to Wildcat Mountain at the north and near Perry Park in the middle. Elsewhere, it is either concealed beneath younger deposits or has been truncated by faulting and does not extend from the subsurface to outcrop. The fan system thins in an eastward direction where interbedded mudstone layers become more prevalent. Raynolds and Johnson (2003) has mapped the general outline of the Wildcat Mountain fan complex that extends from Wildcat Mountain southwest of Sedalia in a northeast direction toward Parker and identifies it as forming the best region of the Arapahoe Aquifer.

Groundwater Flow

Intergranular pore spaces form the primary porosity and permeability and fracturing can enhance permeability locally. A thick accumulation of stacked sand bodies that display great lateral extent into the basin as a result of robust fan development enhance horizontal flow well into the Denver Basin. Vertical permeability may also be high close to the mountain source where mudstone interbeds are less common. Prior to development and under natural conditions, groundwater flow in the Arapahoe Aquifer is

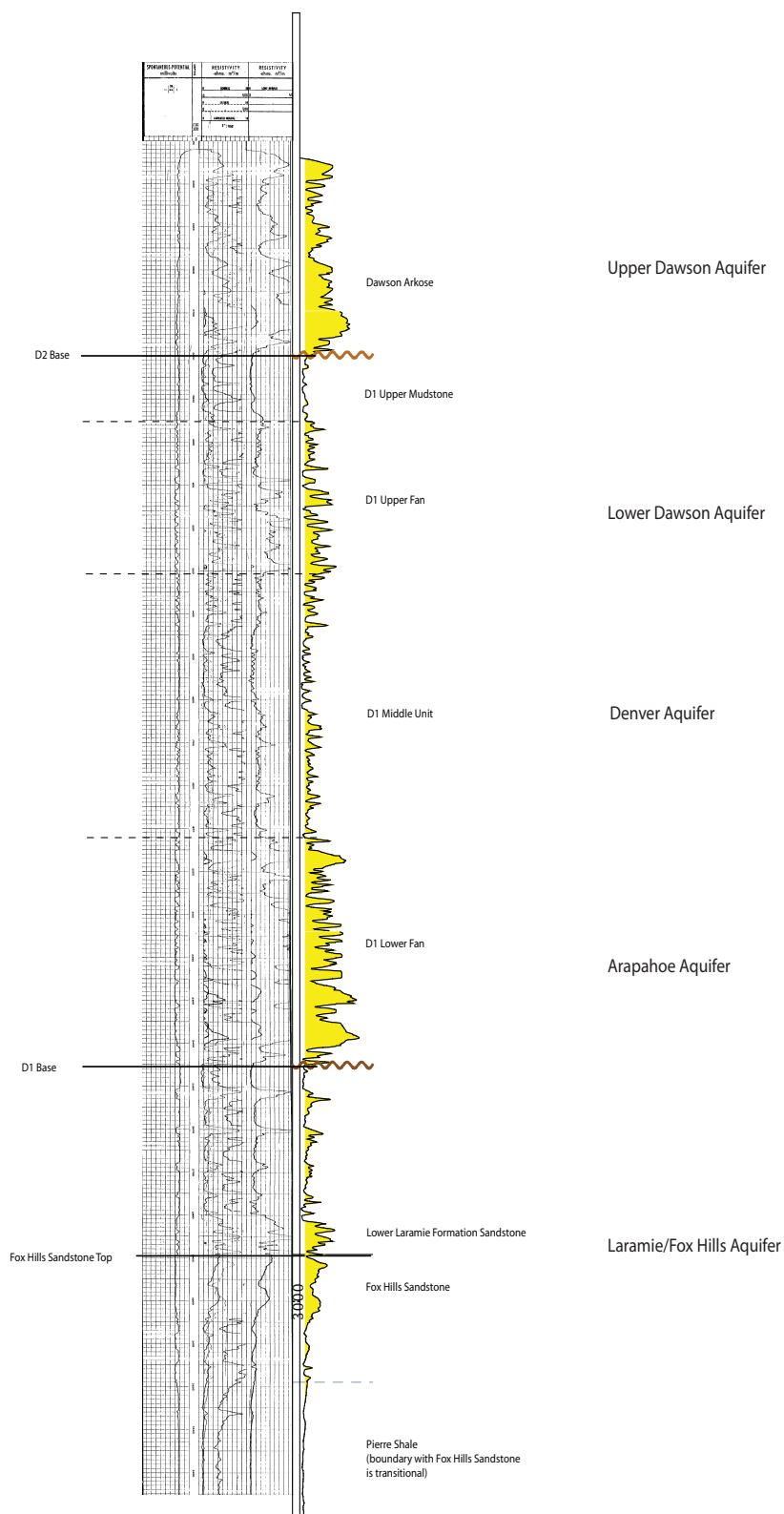


FIGURE 4. TYPE GEOPHYSICAL LOG OF THE DENVER BASIN GROUP. This resistivity and SP log from an exploratory oil and gas well in the southern part of Douglas county (Section 17, Township 10 South, Range 66 West) shows typical curve traces through the interval from the Fox Hills Sandstone into the Dawson Arkose. Resistivity deflections to higher values on the right, highlighted by yellow, indicate sand; deflections to the left indicate mudstone or shale. Noted are the stratigraphic intervals used in this publication. The relative positions of the Denver Basin Bedrock Aquifers as defined by the Denver Basin Rules are shown without noting specific log depths; actual log depths are defined in the Rules and do not always correspond directly to those depths used for correlation in this effort.

estimated to have been generally to the north from Palmer Divide to the South Platte River north of Denver, where the aquifer subcrops the alluvial basin (Paschke, 2011). However, utilization by high capacity wells within the basin has modified that flow. Estimated flow lines from Paschke (2011) are included in Plate 12 that show that groundwater flow lines now converge to the north end of Douglas County where high-production wells supply groundwater to the South Suburban community. Recharge to the aquifer is from direct infiltration at the limited outcrop, including intersections with stream systems and Quaternary alluvium (Plate 12). The greatest recharge, however, is believed to be downward flow from overlying aquifers (Robson, 1987; Paschke, 2011). Discharge is through well pumping and outflow to the South Platte River at the north end of the Denver Basin.

Groundwater Utilization

DWR records include 371 wells designated as Arapahoe Aquifer wells. Of these, 47 percent are permitted for domestic use or household use only; four percent are used for irrigation; and 38 percent are used for commercial, industrial and municipal purposes. Twelve wells are permitted for all beneficial uses and 15 are listed as “other”. Reported depths range from 104 to 3,320 fbs with water levels ranging from 15 to 1,707 fbs. Water levels in the DWR permit database are from the time of well completion. DWR collects water level data from a network of wells in the Denver Basin that are compiled and reported on an annual basis with the most recent set published for 2014 (CDWR, 2014). A detailed discussion of water level trends is beyond the scope of this section. Downward trends over time are common throughout this part of the basin, illustrated in the DWR graphs (CDWR, 2014), reflecting local reliance on groundwater (Paschke, 2011). Reported production rates range from 0.5 to 1,100 gpm.

D1 MIDDLE UNIT

This unit consists of the middle part of the Denver Basin Group D1 sequence (Raynolds, 2002; Dechesne and others, 2011) that inter-fingers with the fan systems originating along the western margin of the Denver Basin (Plate 2). It generally corresponds to strata mapped at the surface as the Denver Formation (Thorson, 2011) where mudstone is more prevalent and fan systems appear less organized in the subsurface. It also generally corresponds to the Denver Aquifer in the subsurface and underlies much of the County within the Denver Basin (Plates 14 and 15). It appears in outcrop at the surface in a belt roughly following West Plum Creek that becomes narrower to the south

where structural dips in the unit become steeper near the Rampart Range fault zone. Correlations of geophysical logs indicate that individual sand bodies within this unit are generally thin with limited lateral continuity, particularly in an eastward direction into the basin (Plate 2).

Groundwater Flow

Intergranular pore spaces form the primary porosity and permeability and fracturing can enhance permeability locally. An increase in mudstone interbeds in this unit restricts vertical permeability. Limited lateral extent of the lenticular sand bodies further to the east also limits horizontal flow. Under natural conditions, groundwater flow in the Denver Aquifer is estimated to have been generally to the north from the Palmer Divide area to the Denver area, where the aquifer outcrops (Paschke, 2011). However, utilization by high capacity wells within the basin has modified that flow. Estimated flow lines from Paschke (2011) are included in Plate 14 that show that groundwater flow lines now converge to the north end of Douglas County where high-production wells supply groundwater to the South Suburban community. Recharge to the aquifer is from direct infiltration at the limited outcrop, including intersections with stream systems and Quaternary alluvium (Plate 14). The greatest recharge, however, is believed to be downward flow from overlying aquifers (Robson, 1987; Paschke, 2011). Discharge is through well pumping and outflow to the South Platte River at the north end of the Denver Basin.

Groundwater Utilization

DWR records include 1,345 wells designated as Denver Aquifer wells. Of these, 85 percent are permitted for domestic use or household use only; one percent are used for irrigation and stock; and 10 percent are used for commercial, industrial and municipal purposes. Ten wells are permitted for all beneficial uses and 10 are listed as “other”. There are 22 monitoring wells. Reported depths range from 43 to 2,556 feet with water levels ranging between 5 and 1,767 fbs. Water levels in the DWR permit database are from the time of well completion. DWR collects water level data from a network of wells in the Denver Basin that are compiled and reported on an annual basis with the most recent set published for 2014 (CDWR, 2014). A detailed discussion of water level trends is beyond the scope of this section. Downward trends over time are common throughout this part of the basin, illustrated in the DWR graphs (CDWR, 2014), reflecting local reliance on groundwater (Paschke, 2011). Reported production rates range from 1 to 750 gpm.

D1 UPPER FAN

This unit consists of a younger fan complex in the upper part of the Denver Basin Group D1 sequence. It overlies and is transitional to the west with the D1 Middle unit consisting of units mapped at the surface as the Denver Formation and lower part of the Dawson Arkose (Thorson, 2011). A laterally continuous interval of mudstone, shown as D1 upper mudstone in Figure 2a and Figure 3, separates this fan complex from the overlying Dawson Arkose. It shares characteristics with the Dawson Arkose above and is sometimes included with the Dawson Arkose where the D1 upper mudstone is not visible at the surface. The fan is better delineated in the subsurface where the D1 upper mudstone can be identified in geophysical logs (Figure 3). The unit generally corresponds to the Lower Dawson Aquifer and underlies the portion of the County within the Denver Basin east of West Plum Creek. It appears in outcrop at the surface in a belt extending along bluffs east of West Plum Creek (Plates 16 and 17). Correlations of geophysical logs indicate that this unit represents a younger well organized fan complex similar to, but not as thick as, the D1 lower fan.

Groundwater Flow

Intergranular pore spaces form the primary porosity and permeability and fracturing can enhance permeability locally. Greater lateral continuity of permeable sand layers out into the basin increases the potential for lateral groundwater flow through the unit, as compared to the D1 Middle unit below. Prior to development and under natural conditions, groundwater flow in the Lower Dawson Aquifer is estimated to have been generally to the north from the Palmer Divide area to the north edge of the County where the aquifer outcrops (Paschke, 2011). However, utilization by high capacity wells within the basin has modified that flow. Estimated flow lines from Paschke (2011) are included in Plate 16 that show that groundwater still flows northward to the outcrop area. Recharge to the aquifer is from direct infiltration at the limited outcrop, including intersections with stream systems and Quaternary alluvium (Plate 16). The greatest recharge, however, is believed to be downward flow from the overlying Dawson Arkose (Robson, 1987; Paschke, 2011). Discharge is through well pumping and outflow to the outcrop.

Groundwater Utilization

DWR records include 1,794 wells designated as Lower Dawson Aquifer wells. Of these, 92 percent are permitted

for domestic use or household use only; five percent are used for irrigation and stock; and 10 percent are used for commercial, industrial and municipal purposes. Five wells are permitted for all beneficial uses and 13 are listed as "other". There is one monitoring well. Reported depths range from 15 to 1,507 feet with water levels ranging between 5 and 780 fbg. Reported production rates range from 3 to 500 gpm.

DAWSON ARKOSE

This unit consists of the youngest fan complex in the Denver Basin Group and corresponds to the D2 sequence of Reynolds (2002) and Dechesne and others (2011). Historically it has been mapped at the surface as the Dawson Arkose (Thorson, 2011). It is separated from the underlying D1 complex by an unconformity that, in places, represents a hiatus of up to 9 million years (Reynolds, 2002), although Thorson (2011) has identified areas near the axis of the basin where there may have been continuous deposition through this period. In places at the surface, an interval dominated by red to yellow colored paleosol in the lower part of the Dawson Arkose forms a good marker bed for the contact with the underlying D1 sequence. In the subsurface, the contact is marked by a sharp contrast in resistivity downward from high resistivity beds of the arkose to low resistivity beds of the D1 upper mudstone (Figure 4). Surface mapping and subsurface correlations have often been ambiguous where the distinct paleosol interval or underlying D1 upper mudstone are not easily identified. This ambiguity becomes more evident to the west where grain size in both the D1 and D2 sequences increases and composition becomes more similar close to the source. The unit generally corresponds to the Upper Dawson Aquifer and underlies the part of the County within the Denver Basin east of West Plum Creek (Plates 18 and 19). It appears in outcrop at the surface over much of the eastern part of Douglas County except where covered by the post-Laramide Tertiary units which are described below.

Groundwater Flow

Intergranular pore spaces form the primary porosity and permeability and fracturing can enhance permeability locally. The Dawson Arkose in this area contains interbeds of mudstone, with thickness and proportion increasing near the base and to the east. However, the overall ratio of sand to shale is high and the unit has relatively high permeability as compared to other Denver Basin Group units. Groundwater flowlines indicate flow to the north and outcrop from the uplands and Palmer Divide. Recharge is from direct infiltration of precipitation and

groundwater discharges to surface water where the unit intersects Quaternary alluvium (Plate 18). Because much of this aquifer is near the surface it also receives recharge from individual sewage disposal systems (ISDS), irrigation return flows, and stormwater runoff.

Groundwater Utilization

DWR records include 2,303 wells designated as tapping the Upper Dawson Aquifer. Of these, 95 percent are permitted for domestic use or household use only; four percent for irrigation and stock; and one percent for commercial, industrial and municipal purposes. Six wells are listed as “other”, four are monitoring wells, and one is a geothermal well. Where reported, depths range from 21 to 905 feet with water levels ranging between 8 and 600 fbs. Reported production rates range from 1 to 75 gpm.

POST-LARAMIDE HYDROGEOLOGIC UNITS

Post-Laramide hydrogeologic units in Douglas County consist of the Larkspur Butte Conglomerate, Wall Mountain Tuff, and Castle Rock Conglomerate. The units tend to be well-cemented and occur at higher elevations on buttes and mesas. DWR well records indicate that the formations are not utilized for groundwater. Their topographic position in the county in higher elevations suggests that they may be drained. Locally, the welded tuff and/or thorough filling of pore spaces of the conglomerates by silica cement may, in places, inhibit direct infiltration to the underlying Dawson Arkose.

ALLUVIAL AQUIFERS

Quaternary alluvial deposits along the modern streams form perhaps the most widespread aquifer system in the County (Plate 20), although total surface area covered is limited. Where present, this system is the most accessible source of groundwater with its shallow depth and relative ease in well drilling and construction.

Alluvial aquifers are composed of sand and gravel deposits associated with modern stream systems. As such the aquifer forms a network of narrow belts along streams, but with wide aerial distribution. Lithologic logs of several wells penetrating alluvium indicate the alluvium generally is less than 125 feet thick and is variably saturated. Water level measurements reported for completed wells range from 1 to 32 feet below land surface.

GROUNDWATER FLOW

Intergranular pore spaces form the primary porosity and permeability. Groundwater tends to flow congruently with surface stream courses. Some recharge is direct infiltration of precipitation combined with return flows from irrigation. Groundwater in the alluvial aquifers is directly connected to surface water and there is also a delicate balance in that connection. Groundwater either receives water as recharge from surface water in a losing stream reach or yields water to surface water as discharge in a gaining stream reach. Active irrigation can affect this balance through pumping from irrigation wells combined with return flows from irrigated lands above the alluvium. Ultimately groundwater in the alluvium discharges down the combined surface stream/alluvial envelope to the main South Platte River system.

Where the alluvial aquifer system intersects bedrock aquifers, there is the potential for hydraulic connection and groundwater flow either from bedrock to alluvium or alluvium to bedrock. This relationship is quite dynamic and depends on several variables including relative head differences between the connected units, hydraulic conductivity of the contact between the units, and water saturation of the bedrock immediately below the alluvium. The hydraulic conductivity of the stream bed of the active stream channel associated with the alluvium also impacts the direct hydraulic connection between stream and alluvium or stream and bedrock, if there is little or no alluvium present. The maps for each bedrock aquifer delineate areas where alluvium intersects the bedrock aquifer and groundwater flowlines show whether the connection indicates flow potential from alluvium to bedrock or bedrock to alluvium. The flow directions are based on relative head elevation relationships and the assumption that there is good hydraulic connection at the intersection.

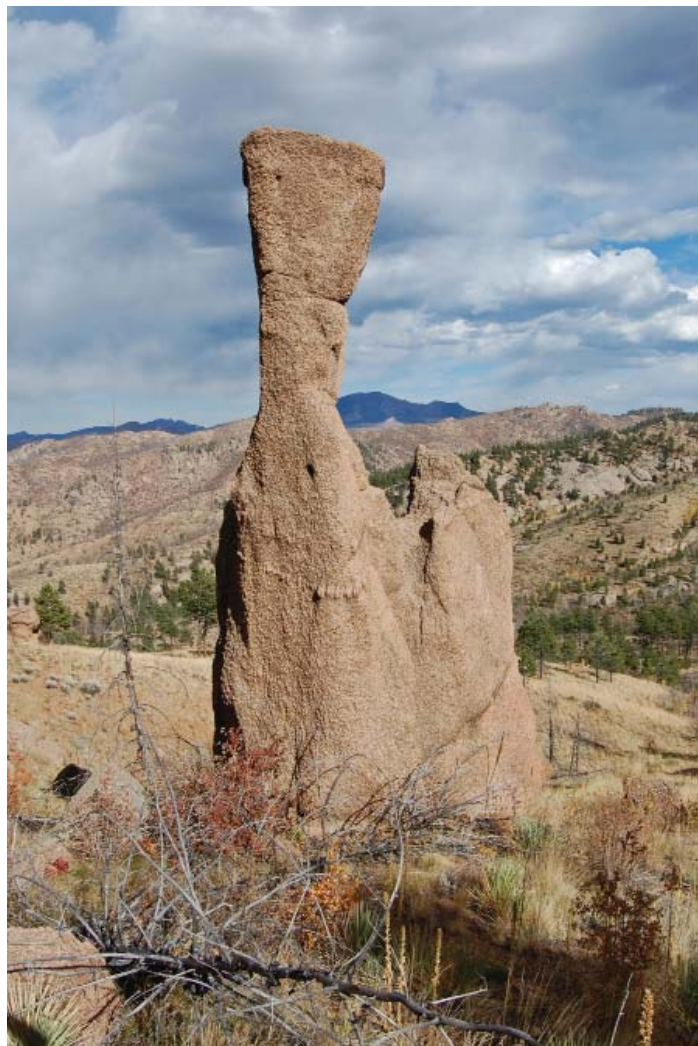
GROUNDWATER UTILIZATION

DWR records indicate that 1,124 wells are completed in the Alluvial Aquifer. Of these, 24 percent are permitted for domestic use or household use only; 16 percent are used for irrigation and stock; and four percent are used for commercial, industrial and municipal purposes. Because of ease of drilling and high transmissivity values in the aquifer, the alluvial aquifer has historically been preferred for high capacity irrigation wells, as reflected in the higher percentage as compared to other aquifers. Twenty-nine wells are listed as “other” and there are two

geothermal wells. The alluvial aquifer is a surficial aquifer and is considered quite vulnerable to contamination. This is reflected in the number of monitoring wells permitted for the aquifer, for which the DWR permit base lists a total of 542, or the remaining 48 percent. Where reported, depths range from 1 to 124 feet with water levels ranging between 1 and 105 fbs. Reported production rates range from 0.14 to 3,000 gpm. The high end of the range reflects the high transmissivity values possible in the unconsolidated aquifer.

OTHER NEAR-SURFACE GROUNDWATER

Development of elevated grasslands and mesas as well as former agricultural land in the County has impacted near surface groundwater in many ways. The most notable effect has been an increase in return flow from widespread landscape irrigation. Many stream courses that were once intermittent, as shown on topographic maps of the area, have become perennial. Indeed, creeks with names like “Dry Creek” now flow continuously. Landscape irrigation in subdivisions increases the amount of infiltration to near-surface soils, many of which are terrace deposits or eolian sand deposits overlying mudstone bedrock. Lower permeability of the bedrock impedes infiltration resulting in perched groundwater conditions. With many newer homes built in areas susceptible to this situation, complaints of wet or flooded basements becomes commonplace. The situation can be most evident in newer areas where residents tend to over-water newer landscaping attempting to establish plantings.



Erosional granite remnant, October 2010. Photo credit: Larry Scott

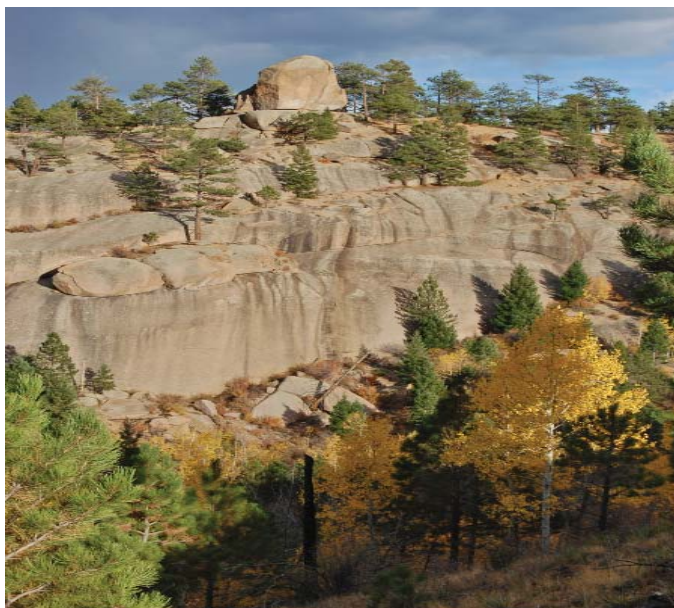
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Cliffs in SW Douglas County, October 2010. Photo credit: Larry Scott