General geology and ground-water resources of the Arkansas Basin in Colorado 1/

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Introduction

The occurrence, quantity, and quality of ground water in the Arkansas Basin in Colorado, as elsewhere, are determined largely by the geology but in part by the climate. In any discussion of the ground waters of this region, therefore, it seems appropriate to begin with a brief review of the events in geologic history that led to the present complex distribution of the many diverse types of rocks now found in the basin, and then to discuss the occurrence of ground water in the different groups of rocks and as related to altitude, climate, water development, and other factors.

Geologic History

Strange as it may seem today, the Rocky Mountain region at the close of what geologists call the pre-Cambrian (nearly a billion years ago) was a vast plain of low relief lying near sea level. This plain was carved during a very long period of erosion on the hardest and most ancient rocks of the region--the granites, gneisses, and schists. During parts of the following Paleozoic era, this plain sank beneath sea level and received sediments now preserved in parts of the area as sandstone (or quartzite), dolomite, limestone, and shale. The absence from this region of some Paleozoic formations found elsewhere tells us that the region alternately sank beneath or rose above sea level several times during the Paleozoic era.

Toward the close of the Paleozoic era and during part of the following Mesozoic era, the region stood above sea level but continued to receive sediments laid down by streams and in inland lakes. The remains of dinosaurs that roamed the region during the Jurassic period are found in the Morrison formation in several parts of the area.

At about the beginning of the Cretaceous period, the region again sank below sea level and remained beneath the sea long enough to receive thousands of feet of sediments now preserved as sandstone, limestone, chalk, and shale. Toward the close of the Cretaceous, the area alternately stood slightly above and below sea level, allowing the formation of vast coal-forming swamps near the shifting coast lines.

At about the close of the Cretaceous, the earth's crust in the Rocky Mountain Region became unstable because of the vast weight of accumulated sediments and there began a series of uplifts accompanied by warping, folding, and faulting of the rocks. As the crest of the major folds or arches rose higher and higher into vast mountain ranges, the forces of erosion began to strip off the veneer of sediments, finally exposing once more and partly dissecting the ancient granitic and metamorphic rocks.

Erosion of the high mountains continued during the Tertiary period, but much of the material removed was spread out by streams, largely over the

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high sloping plain bordering the mountains but in part in intermontane basins. These processes were accompanied by occasional periods of renewed uplift and also by the upwelling of molten volcanic rocks along zones of weakness in the crust created by the folding and faulting. Later renewed uplift again steepened the stream gradients and allowed the streams to strip off much of the veneer of Tertiary sediments.

Widespread climatic changes during the Pleistocene epoch of the Quaternary period caused the formation of alpine glaciers on the higher mountains. The glaciers sculptured the peaks and crests into the beautiful ~~slopes~~ shapes we find today and also created most of the mountain lakes sought out by fishermen and hikers. With the coming of a warmer climate, the glaciers gradually melted, and the swollen streams thus created carried vast quantities of boulders, gravel, and sand that was dropped at favorable localities along the Arkansas River and its larger mountain tributaries. Meanwhile stream erosion that began during the Tertiary was intensified during the Pleistocene to form the many deep canyons and gorges, such as the spectacular Royal Gorge of the Arkansas River. Erosion has continued since the glacial epoch, accompanied by deposition of alluvium along the streams, to form gradually the Arkansas Basin as we find it today--the complex end-product of more than a billion years of earth history.

Ground-Water Resources and Development

The geologic complexity of the area, as described above, obviously precludes the detailed description of the occurrence of ground water in each formation in this short paper; incomplete knowledge of the region also precludes it. General similarities in rock types and physiographic development, however, permit the division of the area into three distinct provinces or sections each having certain peculiar geologic and ground-water characteristics. These are, from west to east, the Rocky Mountain province, the Piedmont section, and the High Plains section--the latter two being parts of the Great Plains province.

Rocky Mountains.--This province includes the headwaters of the Arkansas River and the highest mountain peaks in Colorado along the Sawatch Range, which forms part of the Continental Divide. Other high ranges include the Collegiate Range, Mosquito Range, Sangre de Cristo Range, Culebra Range, Rampart Range, Wet Mountains, and Pikes Peak. The High Spanish Peaks and associated dikes, which are of Tertiary volcanic origin, lie east of the Rocky Mountains in the Piedmont section.

The ancient granitic and metamorphic rocks are exposed over large areas in the Rocky Mountain province, but included also are considerable areas of well-consolidated Paleozoic sediments and Tertiary intrusive and extrusive rocks. Most of these "hard rocks" contain little or no water in the unweathered state, but in the near-surface zone of fracturing and weathering these rocks contain considerable ground water in storage and supply water to many small springs and a few shallow ranch and resort wells. Small areas are underlain by Tertiary sediments which probably yield water somewhat more freely than the older sediments. The most productive water-bearing materials in this province are the extensive deposits of glacial outwash gravel and sand and the alluvium along the Arkansas Valley above Salida. Infiltration galleries that drain water from glacial outwash gravel are used to supply the city of Salida. Generally speaking, however, relatively little ground water is used in most parts of the Rocky Mountain province because of the relative abundance of surface water of good quality, which supplies all large requirements including irrigation.

The bulk of the stream flow comes from melting of snow accumulated

each winter in the mountains, where the annual precipitation ranges from 20 to more than 30 inches. Because of the prevailingly hard rocks in the mountains, the river carries little dissolved or suspended mineral matter where it leaves the mountains at Canon City Although the ground-water reservoirs in the mountains generally are not highly productive, they contain a large quantity of water, and their filling during the spring and their slow discharge during the summer and fall are essential to maintaining the fair-weather flow of the Arkansas River--so vital to downstream water users.

Piedmont section.--Virtually all the Arkansas Basin east of the mountains in Colorado and in a considerable area below Colorado was once covered by a veneer of silt, sand, and gravel laid down late in the Tertiary period by streams draining the Rocky Mountains, such as the Arkansas River and its tributaries. As indicated under Geologic History, however, subsequent uplift allowed the streams to remove this material over wide areas bordering the mountains, and to partly dissect the underlying sedimentary rocks, mainly of Mesozoic age. This moderately dissected gently rolling area is called the Piedmont section. It includes also some areas of Tertiary intrusive and extrusive rocks.

The Cretaceous shale that underlies most of the Piedmont section in Colorado yields only meager supplies of poor ground water to wells and contributes a heavy load of dissolved mineral matter and silt to the streams. Thus the river water below Canon City becomes progressively harder and more highly mineralized until it becomes objectionable for municipal and other uses/ In most parts of the Piedmont section, ground water is not obtainable in large quantities and locally is very difficult to obtain in amounts sufficient for even domestic or stock use.

Somewhat better conditions are encountered in parts of the area where the Cheyenne 3/ and Dakota sandstones are exposed or are within economic reach of the drill. These sandstones supply small to relatively large supplies of soft water in parts of the Arkansas Valley, and yields large supplies to about 10 irrigation wells in the Penrose area near Canon City. The water in these sandstones generally is under some artesian head and in favorable areas in the valley is under sufficient head to flow at the surface. Widespread exploitation in some flowing-well areas in the early days caused diminution or cessation of flow, however, where too deeply buried; these sandstones contain salty water.

Below Pueblo the valleys of the Arkansas River and some of its tributaries are underlain by alluvium that yields moderately large supplies to wells, mainly for irrigation. Terraces are well developed in large areas adjacent to the flood-plain below Pueblo, and where the terrace deposits have been saturated by return flows from surface irrigation, large yields are obtainable from irrigation wells. Of an estimated 645 irrigation wells in the Piedmont section, about 470 wells are along the main stem of the Arkansas River. About 400 of them are in Pueblo and Otero Counties; the rest are in Crowley, Bent, and Prowers Counties. The wells range in discharge from about 400 to more than 1,500 gallons a minute and are used almost entirely for supplemental irrigation. In common with the river water, however, the ground water in the alluvium along the main stem of the river becomes progressively harder and more highly mineralized downstream until it becomes unfit for some purposes. These conditions have created difficult problems of municipal water supply for the towns along the river, most of which generally are faced with the choice of using exceptionally hard water

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3/The Cheyenne is a sandstone member of the Purgatoire formation, but for simplicity it is called the Cheyenne sandstone throughout this paper.

either from the river or from shallow wells in the alluvium. However, a few towns obtain water of better quality from springs or from deep wells that tap the Cheyenne or Dakota sandstones.

There are about 165 known or reported irrigation wells in the larger tributary valleys that are underlain by productive alluvium. Most of these are in the valleys of Fountain Creek and Big Sandy Creek; the rest are in the valleys of the following rivers or creeks, named in order of present known development: Horse Creek, Wet Mountain Valley, Jimmy Camp, Purgatoire, Huerfano, Cucharas, Apishapa, St. Charles, Chico, and Oil. Most of these wells are the sole sources of water for the lands irrigated from them, but a few supply supplemental water only. In general the waters are of better quality than those along the main stem but locally, particularly in areas underlain by the Pierre shale, the waters may be of comparable hardness and mineralization.

High Plains section.--Small remnants of the High Plains have been preserved from erosion in the central and eastern parts of the Arkansas Basin in Colorado. Those in the northeastern and southeastern areas are parts of the main High Plains section that covers much of northeastern Colorado and States to the east and south. An irregularly shaped isolated remnant lies between Big Sandy Creek and the Arkansas River.

Within the remnants of the High Plains section, virtually all domestic, stock, municipal, and industrial water supplies are obtained from wells that tap the saturated lower part of the Tertiary deposits. The water generally is of good quality for most purposes. Inasmuch as the remnants of the High Plains stand higher than the eroded Piedmont section to the west, all ground water in the Tertiary deposits must come solely from the scanty precipitation that falls on the surface of the plains; only a small part of this precipitation actually reaches the ground-water reservoir. Thus the saturated part of the deposits is thin or absent along and near the western escarpment but becomes progressively thicker toward the east, in the direction of the slope.

The thickness of saturation in the isolated remnants decreases to a feather edge also along the eastern and southeastern escarpments where the ground water drains out into lower drainageways cut into the underlying shale. Near the middle of the isolated remnants, however, sufficient saturated water-bearing material may be present locally to supply small to moderate irrigation needs. Greater saturated thicknesses are to be found along old drainageways cut into the underlying shale; hence, test drilling generally is essential to properly locate well sites.

In the northeastern and southeastern areas which extend eastward into Kansas, the general conditions of occurrence are similar to those described above, but generally are more favorable inasmuch as the saturated thickness generally continues to increase toward and beyond the State line.

In the southeastern area conditions seem to be especially favorable for the development of irrigation wells from the Tertiary deposits east of Campo, in southeastern Baca County, and in the area in and adjacent to the valley of Little Bear Creek in northeastern Baca County and southeastern Prowers County. In an area between Two Buttes and Walsh in eastern Baca County, the underlying Cheyenne sandstone supplies about 45 flowing artesian wells having flows ranging from 1 to 100 gallons a minute. Six other wells equipped with pumps yield from 500 to 3,000 gallons a minute and are used for irrigation. Owing to the relatively low permeability of the sandstone, however, a rapid lowering of artesian head accompanies heavy pumping; hence, the artesian area will stand little or no

additional pumping without a serious decline in head. They Cheyenne and Dakota sandstones supply non flowing artesian wells in several other parts of central and eastern Baca County.

Ground-Water Investigations

Until relatively recent years the ground-water resources of the Arkansas Basin in Colorado received very little study, and most of the area still remains to be studied. Most of the old geologic folios of the United States Geological Survey covering parts of the basin contained maps and descriptive material on the artesian water in the Dakota sandstone. The results of these and other studies were compiled in a report by Darton (1906) 4/ covering the occurrence of artesian water in the Dakota sandstone in the entire Arkansas Basin in Colorado. Although these old reports are still usable to a degree, the data are out of date and incomplete, and no attention whatever is given to the younger more prolific water-bearing materials, such as the alluvium, Tertiary deposits, etc. Several old reports of the now defunct Colorado Geological Survey comment briefly on the ground waters of several parts of the basin, but are now of little value. A reconnaissance report by Code (1945) discusses irrigation from wells along the Big Sandy Creek valley.

In 1945 the Colorado Water Conservation Board began a State-wide program of ground-water investigations in financial cooperation with the Ground Water Branch of the U. S. Geological Survey. Although as yet inadequately financed, this cooperative program has included six major investigations and many minor investigations in different parts of Colorado, including three major investigations in the Arkansas Basin by Dr. Thad McLaughlin, assistant district geologist.

The results of the first of these investigations, which covers parts of Lincoln, Elbert, and El Paso Counties, have been published (McLaughlin, 1946). This report gives particular attention to the development of irrigation wells in a part of the Big Sandy Creek valley, but it includes also information helpful to the development of domestic and stock wells in adjacent upland areas part of which are in the Missouri River basin. A detailed investigation of the geology and ground-water resources of Baca County has been completed and the report is nearly ready for publication. A detailed study of the geology and ground-water resources of Huerfano County is nearing completion, and a study of ground-water conditions in the Trinidad area is under way. All these investigations have included test drilling, chemical analyses of ground waters, geologic mapping, inventories of existing wells, and test pumping of selected wells. Observation wells are maintained in each of the areas studied and in important areas to be studied in order to gage the water level in important ground-water reservoirs and give advance warning of possible overdevelopment in heavily pumped areas. In addition, material assistance has been rendered to 13 cities and towns in the basin and to several rural areas in a solution of specific ground-water supply problems.

The ground-water resources of most of the Arkansas Basin in Colorado remain to be studied. It should be emphasized that the full development of the water resources of the Arkansas Basin cannot be achieved until comprehensive studies have been completed of both the ground-water resources and the surface-water resources and their mutual relationships, and also the chemical quality of the waters and the sediment content of the streams. Additional ground-water

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4/See "References" at end of this paper.

studies are needed not only to insure the safe, economic development of known ground-water reservoirs but also to disclose new potential sources of ground water for domestic, stock, municipal, industrial, and irrigation uses and to provide the factual data needed as a basis for the formulation of an equitable State ground-water law.

References

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