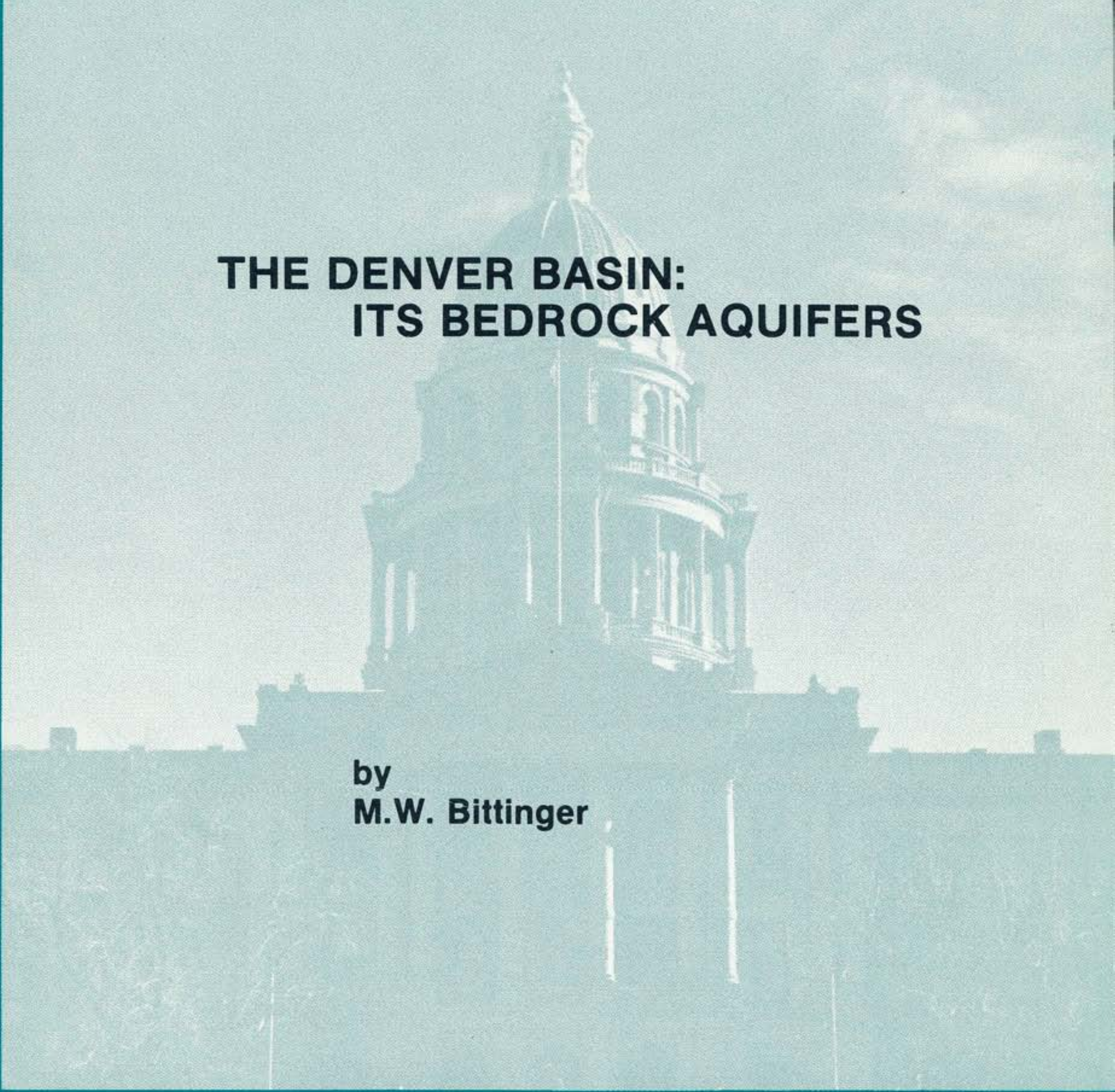

THE DENVER BASIN: ITS BEDROCK AQUIFERS

by
M.W. Bittinger

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> *"Anybody who can solve the problems of water will be worthy of two Nobel prizes - one for peace and one for science."*
>
> John F. Kennedy

FOREWORD

This is one in a series of publications designed to help meet the challenge of providing information on how the natural water system works and how it can be reconciled to the complex demands placed on water by society today. It was prepared by the Colorado Water Resources Research Institute to assist legislators, policy makers, and water resources planners and managers to better understand specific problems and issues.

The most predictable feature of water policy at the present time is change. Changes are occurring in the demands on water supplies, in the values people place on water resources and also in the institutional and legal foundations of public water administration.

This era of change emphasizes water resources administration and management rather than water resources project development. The focus is upon improving management of existing water supplies rather than on the development of new supplies.

Through these publications and other means, the scientists of Colorado's universities hope to meet the challenge of providing information which will be useful in assessing options and impacts or proposed water policy changes.

Norman A. Evans, Director
Colorado Water Resources Research Institute

THE DENVER BASIN: ITS BEDROCK AQUIFERS

The purpose of this paper is to explain the physical structure of the Denver Basin. The explanation should help landowners, developers and legislators better understand the behavior of groundwater in the Denver Basin bedrock aquifers. (An aquifer is a porous geologic deposit containing water that can be extracted.) For instance, a prospective land developer in a certain area of the Denver Basin might wonder why he can't get a subdivision approved or obtain a well permit and use the "ocean" of groundwater that is supposed to be stored in bedrock aquifers. A well owner in that area might point to his falling water level and conclude that there are too many wells. Both persons need to know how the underground storage reservoir works.

What are Bedrock Aquifers?

There are two kinds of aquifers in the Denver Basin; surface deposits of sand and gravel laid down in relatively recent geologic time, and deeper and older deposits of sands and gravels in which the grains have been pressed together and cemented to form rock (sandstone). These latter deposits are called bedrock aquifers. They are interspersed with layers of clay deposits as illustrated in Figure 1.

The Denver Basin bedrock aquifers of interest are the four illustrated in Figure 1: Dawson Arkose, Denver Formation, Arapahoe Formation and the Laramie-Fox Hills.

What is the Denver Basin?

Bedrock aquifers described above form a bowl with the Laramie-Fox Hills member on the outside. The outer edge of the "bowl" extends from near Colorado Springs north along the front range hogback to near Greeley and then south along the eastern boundaries of Adams, Arapahoe and Elbert Counties. Figure 2 shows the approximate location of this boundary.

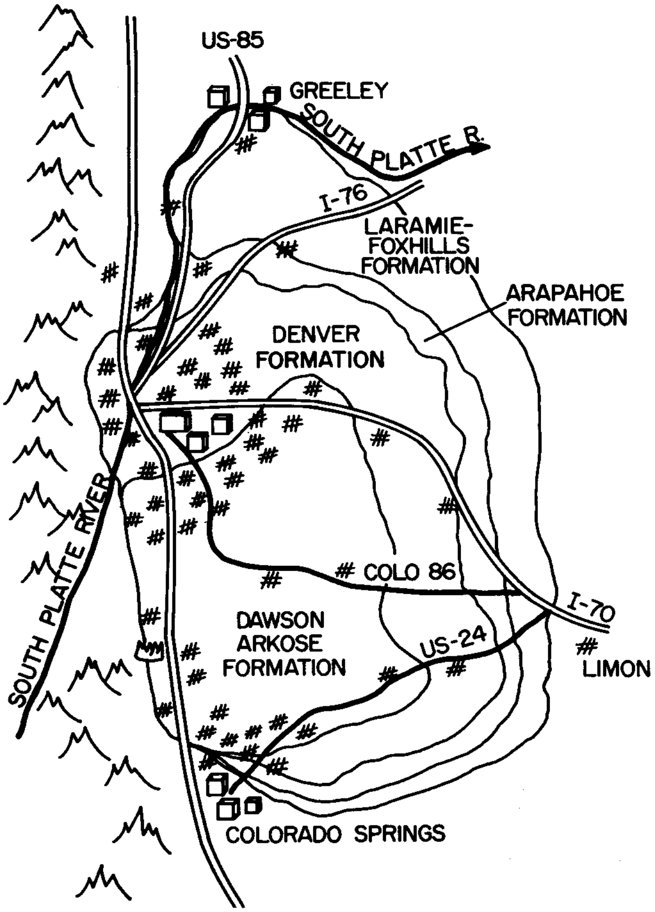

Figure 2.

The land area overlying the Laramie-Fox Hills aquifer is greatest decreasing progressively for the Arapahoe, the Denver and the Dawson Arkose aquifers. Approximate boundaries for those aquifers are also shown in Figure 2. The land area overlying the Laramie-Fox Hills aquifer is about 5,000 square miles;

that over the Dawson Arkose is only about 1,800 square miles. The Dawson Arkose lies almost entirely south of Interstate Highway I-70 and extends eastward to the general area of Kiowa and Calhan. Depending on their location over the "bowl," property owners may have one, two, three or all four of the bedrock aquifers under their land.

What is the Structure and Composition of the Bedrock Aquifers?

Erosional sediments from the mountains were deposited in layers of different composition during the course of several million years. Coarser sands and gravels (subsequently cemented to form sandstone and conglomerate) alternate with clay and shale to form four distinct aquifers. They are represented in Figure 1.

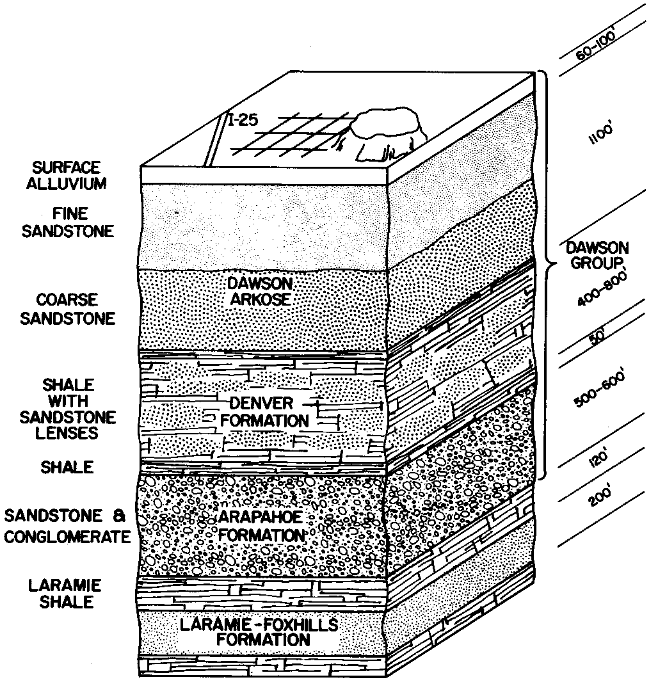

Figure 1.

The lower aquifer, called Fox Hills, is about 200 feet thick and consists of discontinuous layers of sandy shale separated by thin layers of sandstone. The top 50 feet is mostly sandstone.

The Laramie formation, on top of the Fox Hills, consists of alternating thin layers of shale and sandstone. It is about 120 feet thick.

The two similar formations are usually considered a single aquifer and called the Laramie-Fox Hills formation.

Next above them is the Arapahoe formation consisting of sandstone and conglomerate 500-600 feet thick with thin lenses of shale scattered throughout.

A "buffer zone" of shale about 20 feet thick separates the Arapahoe from the Denver formation above it. The Denver is 400-800 feet thick and consists of shale with thick lenses of sandstone scattered throughout.

The top aquifer, the Dawson Arkose formation, is composed of sandstone, 1,000 feet thick. The bottom half is somewhat coarser grained than the top half.

Above these four aquifers lies 60-100 feet of recent alluvial surface deposits. These sediments form shallow alluvial aquifers where they come in contact with streams. Although these aquifers are not generally connected hydraulically with the bedrock aquifers below, there may be contact between them where streams cross the edge of the bowl.

Although each of the four bedrock aquifers is somewhat distinct, they are not completely separated and there is likelihood of exchange of some water between them. Too little data are yet available to assess the degree of hydraulic independence among them.

How Much Water is Stored in the Denver Basin Bedrock Aquifers?

Pores in the aquifers form a storage reservoir which holds a large volume of water. Unlike surface reservoirs which receive annual replenishment from precipitation runoff, the Denver Basin bedrock aquifers receive only a small amount of replenishment each year. The situation is analagous to a large bank account from which many people are withdrawing but are making essentially no deposits. Obviously, the supply one day will run out.

In this case, the usable bank account is estimated to be as much as 150 million acre-feet of water. There are as many as 300 million acre-feet of water in the four aquifers but only about 50 percent is estimated to be recoverable.

One hundred fifty million acre-feet of water is a valuable resource in a semiarid region that has a rapidly growing population. Tough questions that people and their legislators must ask are: How rapidly should the water be used?; and, what criteria will determine who should use the bedrock aquifer water and who should be denied its use.

How Much is Added to and Removed From the Denver Basin Bedrock Aquifers Each Year?

According to records kept by the Division of Water Resources, more than 6,500 wells draw water from the Dawson Arkose, Denver, and Arapahoe formations and about 700 wells tap the deeper Laramie-Fox Hills aquifer. These are mostly small capacity livestock and domestic wells, but in recent years an increasing number of municipal, commercial and industrial wells have been drilled. The Denver Basin bedrock aquifers furnish the sole supply of water to about 40 municipalities and water companies or districts. Another 10 water agencies supplement surface water supplies with bedrock aquifer water.

It is estimated that at least 125,000 acre-feet of water per year is pumped from the upper three aquifers (often called the Dawson group) and 18,000 acre-feet of water per year from the Laramie-Fox Hills aquifer. Total water removed from the four aquifers per year is estimated to be 150,000 to 160,000 acre-feet.

The precise annual recharge to the aquifers is not known. Recharge occurs primarily around the rim of the bowl from precipitation on aquifer outcrop areas and from surface streams crossing the exposed formations. A study in progress by the Colorado Division of Water Resources will improve estimates of the amount of recharge, but there is no doubt that the recharge amounts are small, probably less than the annual volume of water being pumped from the aquifers.

Are the Denver Basin Bedrock Aquifers "Artesian"?

The words "artesian" and "confined" are often heard in discussions of the Denver Basin bedrock aquifers. The words can be used interchangeably. They mean that water contained within the aquifers is under pressure. Pressure is developed because the aquifers are confined above and below by deposits of impermeable clay and shale (Figure 3). Pressure in the aquifers is caused in the same way as pressure in a pipeline connected to a standpipe or elevated tank

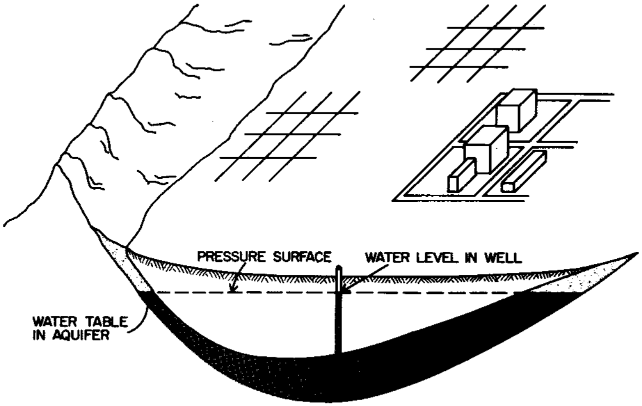

Figure 3.

containing water. Because of the bowl shape of the Denver Basin bedrock aquifers, water levels around the rim stand at higher elevations than the lower part of the bowl. This creates pressure in the lower part. If a well is drilled into one of the aquifers in the lower part of the bowl, the water level will rise in the well above the top of the aquifer. The amount of rise above the aquifer represents the amount of pressure in the aquifer. An imaginary surface above the aquifer connecting levels to which water would rise in wells is called a pressure surface.

During the early days of groundwater development in the Denver Basin bedrock aquifers, the water pressure surface in each aquifer was above the land surface and water flowed at the surface without pumping. Early wells serving downtown Denver businesses were flowing artesian wells.

Are the Aquifers Hydraulically Independent?

Since the four bedrock aquifers are separated from each other by layers of clay or shale, they respond to pumping and recharge somewhat individually. However, the confining or separating layers are not without gaps, so there is a certain amount of hydraulic connection between the aquifers. Pressure change in one aquifer may affect the pressure locally in an adjoining aquifer, and some water may flow from one aquifer to another.

A 5-6 year study recently initiated by the U.S. Geological Survey, in cooperation with the Colorado Division of Water Resources, will help define the pressures in each of the four aquifers more fully than is now possible. Observation wells in each of the aquifers are being established for measuring and monitoring water levels. This study will also be helpful in evaluating the present and potential interchange of water between aquifers resulting from differences in pressures, a question which cannot be answered with presently available information.

How Have Aquifer Pressures Changed Over the Years?

As more and more wells were drilled into the Denver Basin bedrock aquifers and the volume of extracted water grew, pressure in each aquifer dropped.

There have been pressure declines of as much as 50 feet per year in wells tapping the Laramie-Fox Hills aquifer in the Brighton-Northglenn area. Losses of pressure in that aquifer have been greatest in the metropolitan areas and the South Platte River Valley north of Denver. Areas where the intensity of pumping is less have experienced smaller declines.

Water levels and artesian pressures also have declined in the upper three aquifers. As much as 200 feet of pressure surface decline has been experienced in the Arapahoe formation near the Cherry Creek Reservoir and about 100 feet of decline has occurred in the Northglenn area.

It is thought that the first artesian well was drilled in 1883 in the downtown Denver area and that it had a pressure sufficient to raise water 200 feet above the land surface. Thus, the well flowed without pumping. Now, in the same vicinity, the water level in wells is at least 450 feet below the land surface, a pressure decline of about 650 feet.

Why Aren't Pressures Everywhere the Same Throughout an Aquifer?

The fact that pressure in an aquifer varies from place to place is a source of much confusion. We all know that water "tends to seek its own level." Therefore, it would seem logical that pressure in the aquifer would be the same everywhere. This would happen if water could move very fast in the aquifer.

But this is not possible. Pore spaces in the sandstone are small and flow paths are tortuous; thus, the water moves very slowly.

When a well is pumped, pressure in the aquifer immediately around the well is reduced. It is the difference in well pressure compared to pressure in the aquifer at some distance from the well which drives the water toward the well when it is pumped. Pressure surface around the well can be visualized in the form of an inverted cone centered on the well (Figure 4). This is often described as a "cone of depression."

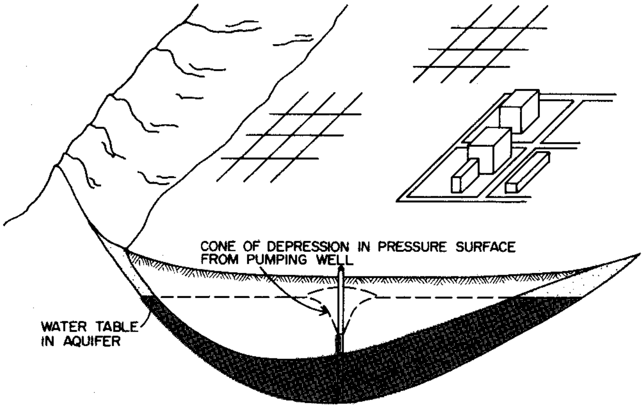

Figure 4.

When several wells in an area are being pumped, cones of depression of the adjacent wells may merge. This merging reduces the pressure difference between the well and aquifer nearby and, therefore, reduces the rate at which water flows to the well. Consequently, the rate of discharge from the well also is reduced. Further, merging of the cones of depression tends to cause a general lowering of water pressure surface in areas of concentrated pumping, as illustrated in Figure 5. The size of the area of influence of the pumped wells is affected by the flow resistance in the sandstone mentioned above, but other physical features such as faults or discontinuities in the aquifer also may affect it.

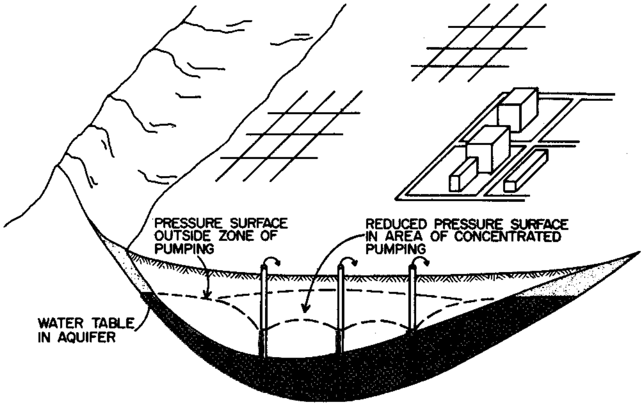

Figure 5.

Why are Pressures Different in Each Aquifer?

Figure 6 illustrates the rim of the Denver Basin "bowl" with hypothetical current water tables shown for each aquifer. Field data are not adequate presently to fix their true location, but they are assumed at different elevations due to different pumping rates in the aquifers.

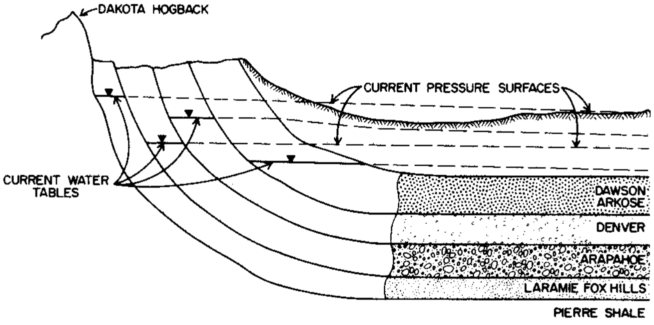

Figure 6.

The pressure surface for each aquifer is determined by the elevation of the water table as illustrated by dashed lines.

Before pumping began, the water tables were probably at the same elevation in all aquifers and therefore the pressure surfaces were also the same. This pressure surface was above the land surface so that the first wells would flow without pumping. Today the pressure surfaces for all aquifers except the Laramie-Fox Hills are below the land surface and wells in these aquifers must be pumped.

Why do Certain Adjacent Wells have Different Pumping Lifts?

Adjacent wells drilled into different aquifers may have different pumping lifts depending on pressure in the respective aquifers as well as on permeability of the aquifer. Figure 7 illustrates two wells pumping from different aquifers. The Arapahoe and the Denver formations. Although the water table and pressure surface in the Arapahoe is lower than in the Denver, the pumping lift in the Arapahoe well is less because water flows more easily in its sandstone and the drawdown of its pressure surface is less.

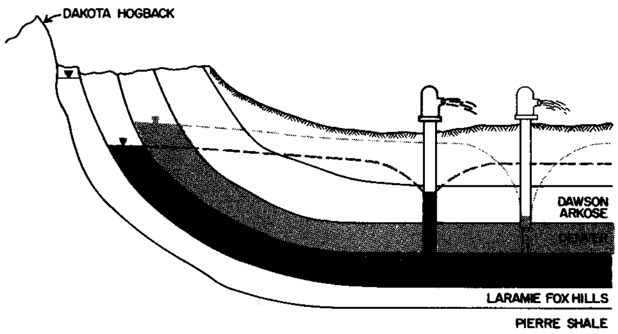

Figure 7.

A second reason is illustrated in Figure 5 where a concentration of wells is shown to lower the general pressure surface over an area of influence. A well outside this area would have the advantage of higher pressure and thus a smaller pumping lift.

What Impacts can be Expected on Wells Due to Increased Pumping?

Two kinds of impacts may be expected. The first is a drop in the elevation of the pressure surface for each aquifer and a corresponding increase in pumping lift. This places a burden of increased pumping cost on affected wells. Well owners may be forced to deepen the wells and/or lower pump bowls for example. However, the wells will continue to produce until the decline in pressure is extreme enough to cease delivering water into the well.

The second kind of impact would occur around the edge of the basin where the aquifers tilt upward to the surface. Relatively shallow wells into the aquifers would be "dried up" first as the water table drops.

Are the Bedrock Aquifers Connected to the Surface Alluvial Aquifer?

In general, the four Denver Basin bedrock aquifers are hydraulically separated from the sand and gravel deposits on the surface. Deposited in watercourses by flowing water, these shallow alluvial aquifers are connected to surface streams and are a very important source of pumped water. There are thought to be some locations where hydraulic connection exists between the bedrock aquifers and these alluvial aquifers, but the amount of water exchange between them is probably very small.

What Laws Pertain to the Denver Basin Bedrock Aquifers?

Until 1973 there was no specific legislative authority or direction given to a state agency to regulate well drilling in, and groundwater use from, bedrock aquifers. The Groundwater Management Act of 1965 and the Water Rights Determination and Administration Act of 1969 pertained to specific groundwater situations in Colorado but not to bedrock aquifers.

The statute passed in 1973 (Section 37-90-137 [4] CRS 1973), commonly referred to as Senate Bill 213, set the "useful life" of each bedrock aquifer at 100 years and gave the State Engineer authority to issue well permits based on the quantity of water underlying an applicant's property. In practice, the amount of water in the aquifer underlying an applicant's property is determined by the thickness of the aquifer and the percentage of the volume of the water stored in the aquifer that is recoverable. This volume of water is divided by 100 to arrive at an allowable annual pumping volume. A permit may be reduced or denied to prevent "material injury to vested water rights."

Can a Pumping Regulation Developed for the Denver Basin Bedrock Aquifers be Applied elsewhere in Colorado to the same Aquifers?

The Denver Basin is unique in its bowl form and in its hydrology. Although the four bedrock aquifers are found elsewhere in Colorado, they do not occur in this particular shape as far as is known. Their physical composition and hydraulic characteristics may be about the same elsewhere however.

They are recharged by seepage from surface waters which enter the aquifers at certain places around the edge of the bowl. But at the same time, there is leakage from the aquifers into surface waters at certain places around the edge of the bowl.

Furthermore, the four aquifers are hydraulically interconnected to some degree. The amount or rate of water exchange between them under current or prospective pumping rates is unknown; but it would be a factor in an effective pumping regulation for the Denver Basin. This factor may not be the same at other locations.

If a pumping regulation were designed to meet a certain objective in the Denver Basin, it might not have the same result when applied at another location. For example, if the objective were one which takes into consideration the hydrology of the Basin, then the regulation would not likely be equally applicable elsewhere.