COLORADO DEPARTMENT OF NATURAL RESOURCES

ROCKTALK

Division of Minerals and Geology
Colorado Geological Survey

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GROUND WATER IN COLORADO— A PRIMER

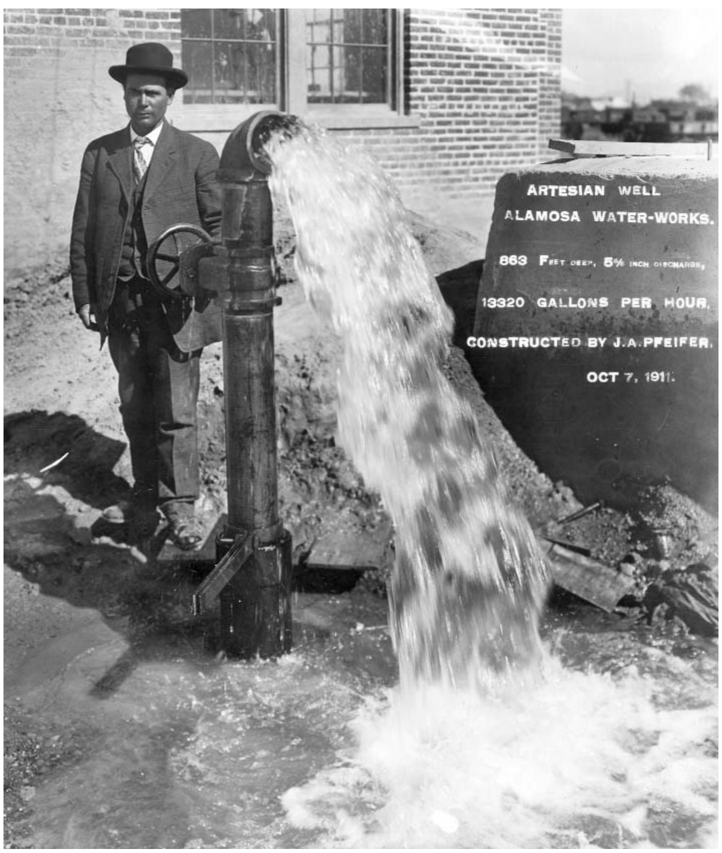
Introduction

One of the most compelling issues in Colorado today is the availability of long-range water supply. Between 1990 and 2000, Colorado grew from 3.3 to 4.3 million persons. This accelerated growth in conjunction with the continued popularity of our state has focused the attention of our citizens, legislators, and water managers on the water resources required to sustain our wildlife, communities, and businesses. Demands on Colorado's water supply run the gamut from domestic and agricultural to provisions for recreational and wildlife uses. Historically, development throughout the semi-arid west has been dependent upon the availability of water.

With its ready access and storage capability, surface water has and continues to provide the bulk of our state's water supply. Over-appropriation of this resource, however, combined with rapid urban growth and a lack of suitable future storage reservoir sites, has drawn attention to our ground-water resources. Ground-water use in Colorado dates back to before the turn of the century (photo below). Ground-water resources currently supply approximately 18 percent of our state's needs and its development is continuing at a fast pace.

Nineteen of Colorado's 63 counties rely solely on ground water for potable supplies and domestic uses. Ground-water withdrawals by private wells and public water supply systems serve an estimated 20 percent of the state's population. Colorado's agricultural industry relies heavily upon ground water, particularly on the eastern plains and in the San Luis Valley. Approximately 90 percent of ground-water withdrawals are consumed by agriculture.

The balance between supply and demand for water is a delicate one. Though a renewable resource, ground water is not always available in the quantity or quality when and where it is needed. With creativity, a history of diligence, and some planning of its water resources, Colorado has supported a large agricultural industry, expanded



Artesian well at Alamosa Water works, 13,320 gallons per hour, constructed by J.A. Pfeifer, October 7, 1911

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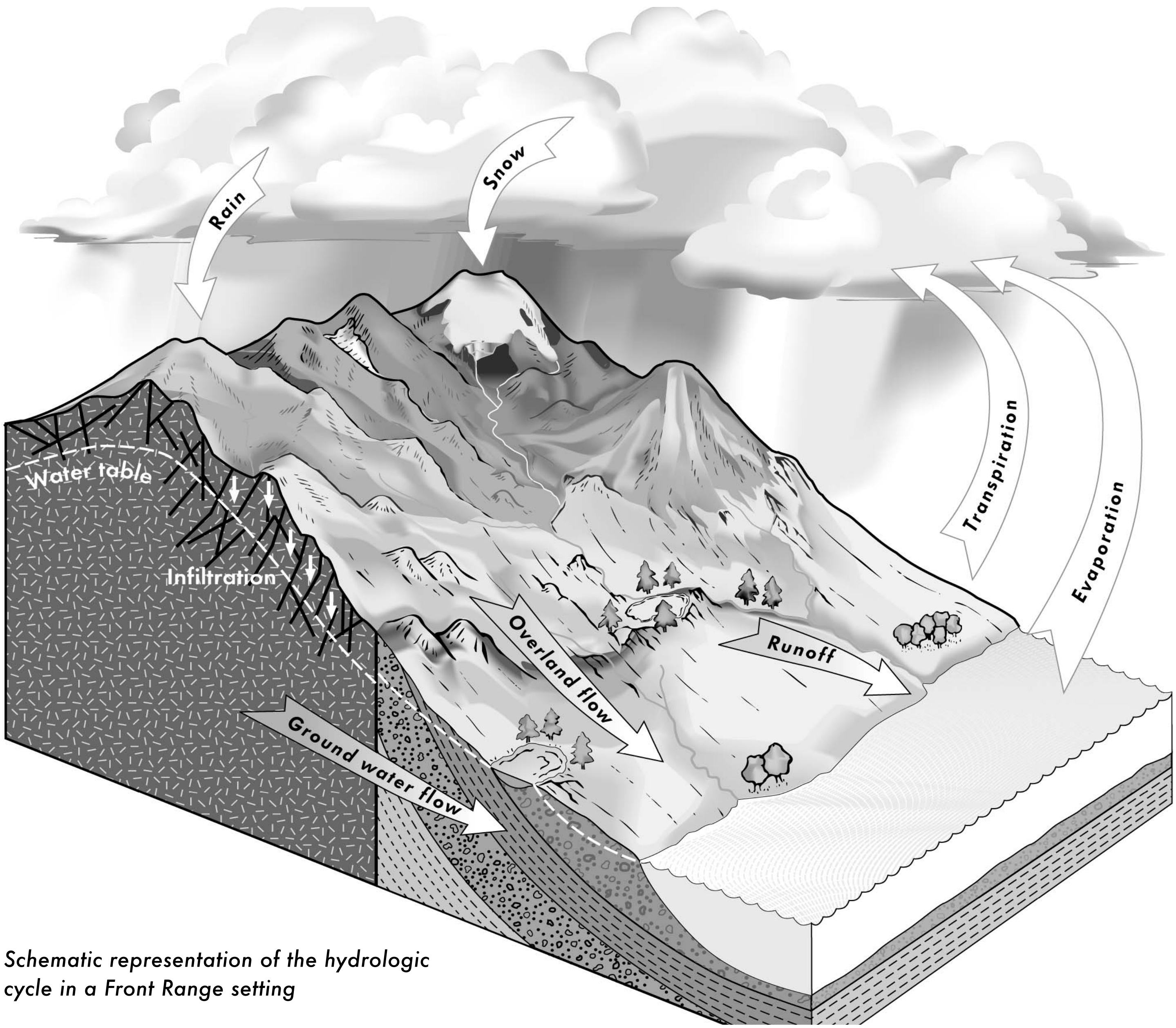
INSIDE

urban population centers, created a diverse and popular recreational industry, and maintained a quality lifestyle for its citizens within the constraints of a thirsty, semi-arid climate. Through wise water-management policies, protective regulations, and conservation activities we can assure ground water's availability and suitability for future use.

Ground-water Hydrology

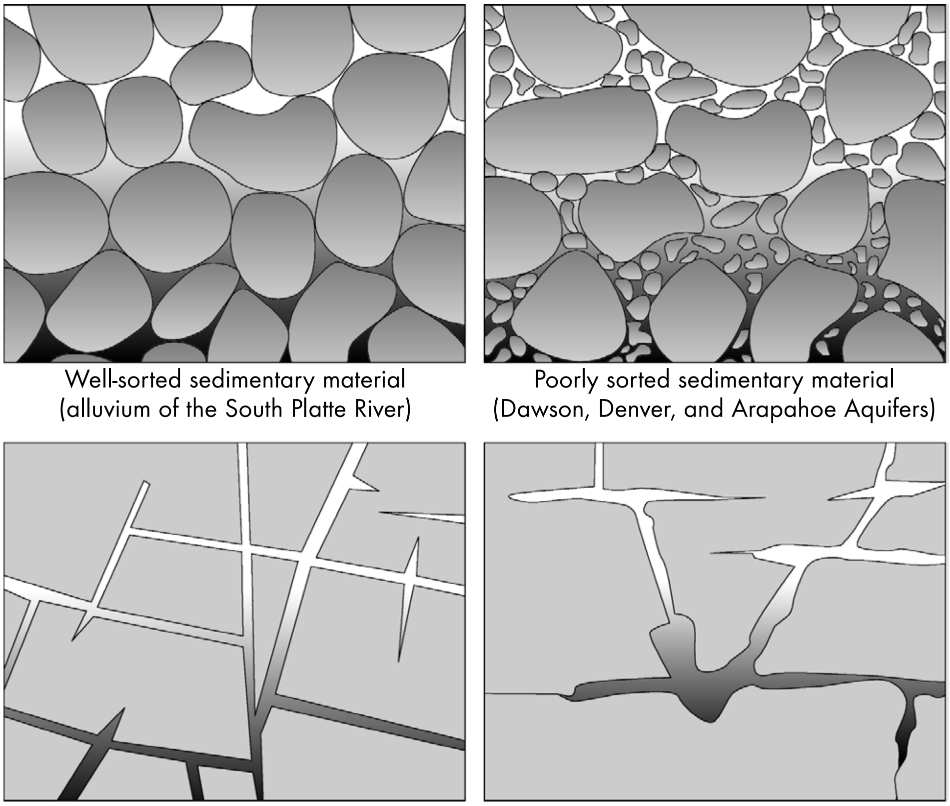
For all practical purposes, ground water is all water beneath the surface of the earth (as opposed to surface water). Ground water hydrology, or hydrogeology, is an interdisciplinary science that deals with the occurrence, movement and quality of water beneath the Earth's surface.

The ultimate source of ground water is precipitation (in the form of rain, snow, or hail) that does not evaporate or immediately flow to rivers, streams, or lakes, but percolates into the ground. The concept of the hydrologic cycle is central to understanding the occurrence of ground water. The hydrologic cycle, as the name implies, is an endless dynamic process of the circulation of water between the atmosphere, the oceans, and the land. The basic inputs and outputs of the hydrologic cycle are shown schematically in diagram below. These processes include evaporation, transpiration, precipitation, overland flow, infiltration, runoff, and ground-water flow. While dependent upon the elevation, ground cover, and type of vegetation, approximately 81 percent of the precipitation that falls in Colorado returns to the atmosphere through evapotranspiration (evaporation from exposed moist surfaces and transpiration from vegetation).



Schematic representation of the hydrologic cycle in a Front Range setting

Common Aquifer Materials



Well-sorted sedimentary material (alluvium of the South Platte River)

Poorly sorted sedimentary material (Dawson, Denver, and Arapahoe Aquifers)

Fractured crystalline rocks (Pikes Peak Granite)

Soluble rock forming material (Leadville Limestone)

Water movement in the subsurface cannot be seen or measured with the certainty that surface flow can, and thus its occurrence is not as precisely understood. This aspect of ground water also produces many misconceptions; many people think of it in the form of underground lakes and streams. Most ground water occurs as water filling pore spaces between rock grains in sedimentary rocks or in crevices such as fractures and faults in crystalline rocks. Openings that exist in rock and soil, such as pore spaces between grains of sand and silt, between particles of clay, or along fractures in crystalline rock, represent a tremendous volume when taken in aggregate. These water-filled pores or fractures represent the zone of saturation, which man has tapped for water supply since early civilization. The top of the zone of saturation is termed the water table.

Some materials have a greater ability to store and transmit water than others. The amount of water a material can hold depends upon its porosity—the ratio of void space to total volume. Geologic units consist of either unconsolidated sediments or consolidated rock. Porosity in granular deposits such as sands or gravel may exceed 40 percent of the total rock volume, while fractured, crystalline rock porosity may be one percent or less. The size and degree of interconnection of those openings, or permeability, determine the materials' ability to transmit fluid. The most productive aquifers in the world are composed of unconsolidated sand and gravel and cavernous carbonate rocks.

An aquifer is a ground-water reservoir composed of geologic units that are saturated with water and sufficiently permeable to yield water in usable amounts to wells

field notes from the director

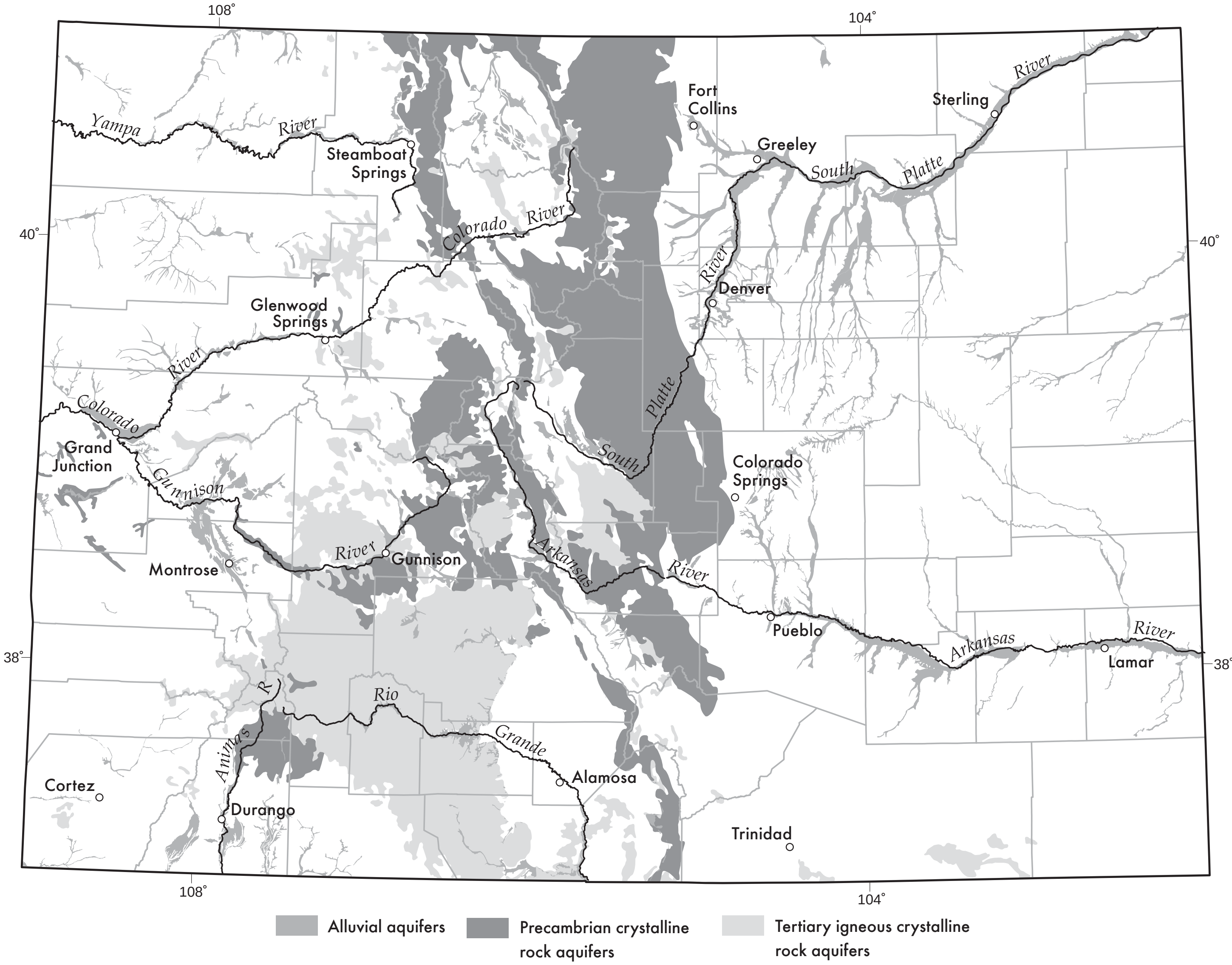
WATER AND ROCKS

A recent article in the *Rocky Mountain News* (September 14, 2002, p. 25A) described a survey the paper conducted of water users in the Denver metropolitan area. The newspaper reported that the residents within the 44 water districts of the seven counties around Denver used an average of 74,410 gallons per person during 2001. Along with the 2.5 million residents of the Denver area, Colorado also needs water for the other 1.8 million people in the rest of the state, and its industrial and agricultural uses. We now know that much of our state is in its fourth year of drought, and that reservoirs that provide water to the Denver area are at about 50 percent of capacity as we go into the winter season. When we look at all of these facts together, it is no surprise that everyone is talking about water in Colorado this year.

But what does geology have to do with water? Why are the scientists at CGS writing about water?

In fact, geology is extremely relevant to water, and good understanding of geology contributes to a better understanding of our water quality and quantity. Such knowledge can, in turn, lead to better ways to protect, conserve, store and manage water. Consider the geology of any water system, surface or underground, as the vessel that contains the water. The shape, size, and physical and chemical characteristics of that vessel, or the rocks holding the water, play

from the director continued on p. 15



Alluvial and crystalline rock aquifers of Colorado

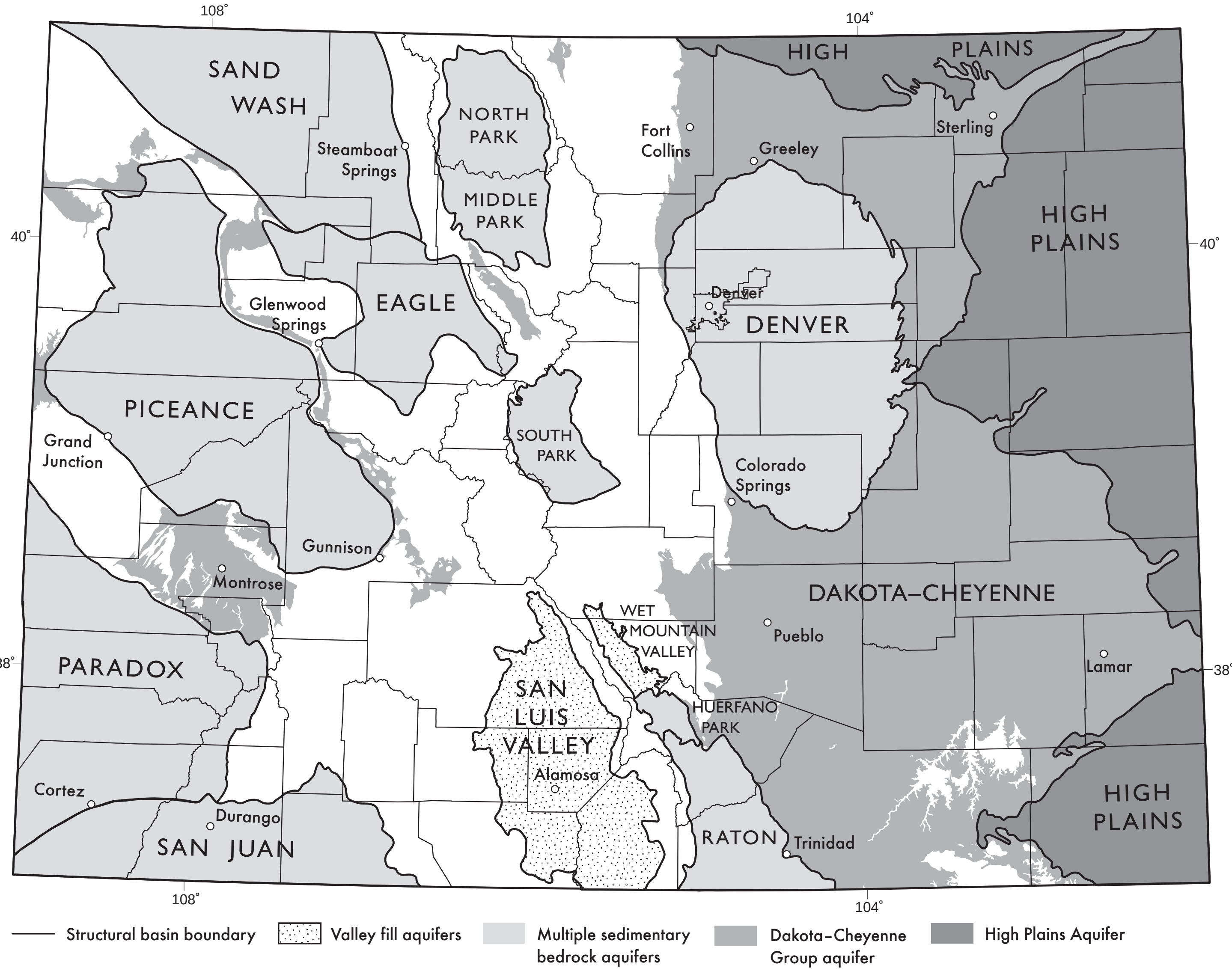
and springs. Sand and gravel deposits, sandstone, limestone, and fractured crystalline rocks are examples of geologic units that form aquifers. The porosity and permeability of these common aquifer materials are depicted in the illustration on page 3. Aquifers provide two important functions: 1) they transmit ground water from areas of recharge to areas of discharge, and 2) they provide a storage medium for useable quantities of ground water.

Aquifers that are not completely saturated with water are termed unconfined aquifers. Unconfined aquifers provide water to wells by draining the pores and/or fractures of the geologic material surrounding the well, and are recharged by water infiltrating and percolating through the unsaturated zone. The saturated alluvial deposits associated with many of the river systems in Colorado, such as the South Platte, Arkansas, and Colorado Rivers, and valley-fill deposits such as the San Luis and Wet Mountain Valleys are examples of unconfined aquifers.

Confined or artesian aquifers are completely saturated, permeable geologic units overlain by relatively low permeability confining layers, such as clay and shale, that prevent free movement of air and water. The water is, thus, confined under pressure and if tapped rises to an elevation above the top of the aquifer, but not necessarily above the land surface. Confined aquifers yield water by compression of the aquifer soil or rock, expansion of the water, drainage of adjacent unconfined portions, and leakage through confining layers. For the most part, the Denver, Arapahoe, and Laramie-Fox Hills aquifers of the Denver Basin are examples of confined aquifers, where they are overlain by impermeable layers.

Colorado's Aquifers

Aquifers can also be defined in terms of their geologic materials. The geology and geography of



Principal sedimentary aquifers and structural basins of Colorado

Colorado is the foundation of the state's water resources. You might say, "Geology guides ground water." The geologic story deciphered from the rocks of Colorado recounts multiple structural events raising mountain ranges, later eroded and partially buried in their own debris, shallow seas with their associated beaches sweeping across the land, and deserts undulating with dune fields. In more recent geologic time, the rocks tell of large active volcanic fields that seared a land dominated by deltas and swamps with lava and volcanic ash. Over much of Colorado, the landscape resulting from this geologic history has been modified by the work of glacial ice that scraped off mountain peaks and scoured valleys, leaving thick layers of accumulated sediments across the land as glaciers retreated and melted.

This complex geologic history has divided the state into fractured, crystalline rock mountain ranges; deep basins and fault-bounded valleys as well as areas of relatively undisturbed flat lying sedimentary deposits. Colorado's principal aquifers are categorized into: 1) unconsolidated Quaternary-age alluvial aquifers associated with our major river systems, 2) poorly consolidated or unconsolidated sediments, 3) consolidated sedimentary rock aquifers, and 4) volcanic and crystalline rock aquifers.

Alluvial aquifers are unconfined and contain ground water stored in stream-deposited unconsolidated sediment along river valleys. Ground water in alluvial aquifers usually interacts with surface water of the stream system, and ground-water levels may exhibit seasonal variation in response to surface-water flow. Perched or confined ground water can also occur in alluvial aquifers if clay layers are present in the stream sediments. Alluvial deposits associated with ten of Colorado's major river watersheds,

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listed below, are illustrated on the map on page 4: South Platte, Republican, Arkansas, Colorado, Yampa, White, Gunnison, San Juan, Dolores, and Rio Grande.

Sedimentary rock aquifers are composed of consolidated clastic and carbonate deposits. Ground water in sedimentary rock aquifers can be either confined or unconfined. The major sedimentary rock aquifers in Colorado consist predominantly of sandstones and limestones of varying age. Many of these aquifers are located in structural basins that contain multiple geologic units/aquifers. Large quantities of ground water occur in deep basins such as the Denver Basin and in the flat-lying High Plains Aquifer of eastern Colorado. Basin-wide aquifer systems, illustrated on the map on page 5, include the: Denver, Piceance, Paradox, San Juan, Eagle, Raton, and Sand Wash Basins; and North and Middle Park, South Park, and Huerfano Park.

The intermontane valleys of central Colorado contain a network of hydraulically interconnected aquifers within valley-fill deposits. These unconsolidated to poorly-consolidated aquifers consist of sediments that were deposited by wind, water, and gravity, such as landslides from erosion of the surrounding mountain ranges. Similarly, the Great Plains of eastern Colorado are underlain by a thick sequence of gravel, sand, silt, and clay that was eroded from the Rocky Mountains. These poorly-consolidated, often localized, sedimentary aquifers include the San Luis Valley, Wet Mountain Valley, and High Plains Aquifer.

Lastly, Colorado's crystalline rocks are exposed at the surface in the west-central portion of the state (see map on page 4). The crystalline rocks throughout this province are Precambrian-aged igneous and metamorphic rocks; largely granites, gneisses, and schists; and geologically recent (Tertiary age) volcanic and igneous intrusive rocks. Ground water in crystalline-rock aquifers is generally unconfined, and occurs where joints, fractures, and faults have crosscut the rock. These rock types occupy approximately 19 percent of the state's total area, and represent the fractured, crystalline-rock aquifers that supply much of the domestic water-supply needs in the mountainous portion of our state.

As Colorado's population grows, the importance and use of ground water also grows. The CGS is in the process of compiling a *Ground Water Atlas of Colorado* that will describe each of these major aquifers or aquifer systems, addressing individual hydrogeologic units, their hydraulic characteristics, principal water uses and withdrawals, and a brief look at water quality. When complete in early 2003, this atlas will provide important information useful to farmers, ranchers, homeowners, businesses, and decision-makers in Colorado.

—Ralf Topper

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THIS ISSUE
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Ground Water Resources in the Time of Drought

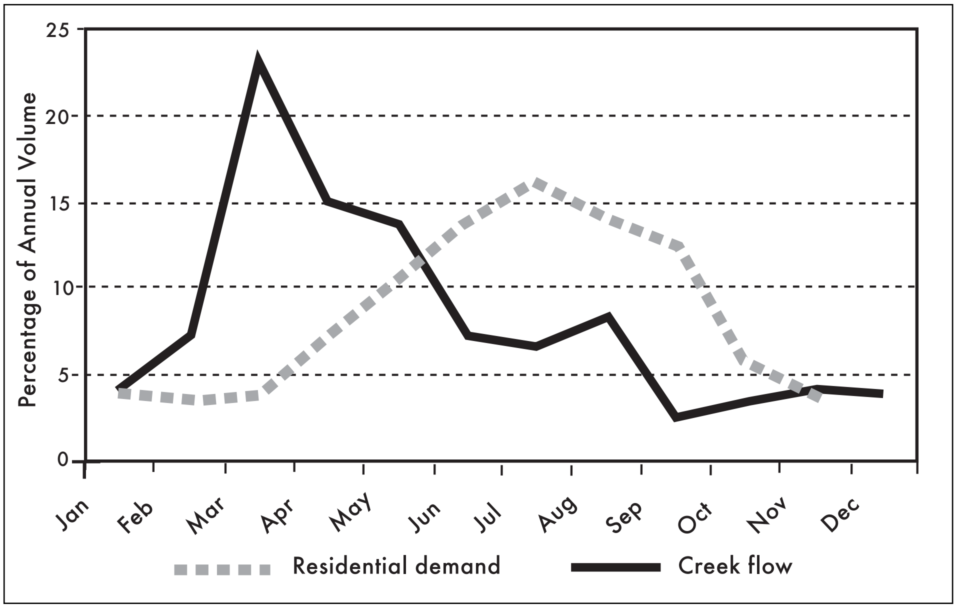
Colorado is in the midst of a record-breaking drought. Stream flows across the state are at all-time lows and reservoir levels are falling fast. Water restrictions are popping up in every community as lawns and trees are turning brown. While surface water comprises the major portion of Colorado's water supply, ground water cannot be overlooked for its role in times of drought, particularly as it can be utilized to supplement surface-water supplies.

First, it is important to understand what drought is and how it plays into the delicate balance of supply and demand. It is also important to understand ground water and how it interacts with surface water. Moreover, there is the legal framework within which water rights are administered that has to allocate this periodically scarce resource.

Drought is a shortage of water that begins as **meteorological drought**, where precipitation falls below "normal" for an extended period of time. It can then extend to **agricultural drought**, where soil moisture levels drop to the point where vegetation is stressed, reducing biomass and yield. **Hydrological drought** develops when there is reduced streamflow, reduced inflow to reservoirs, lakes and ponds, and reduced recharge to ground water. This can ultimately lead to **socioeconomic drought** when demands exceed supply, negatively impacting human activity. Ground water resources can be called on to mitigate the progression of precipitation shortfalls to socioeconomic drought. Timing is a key factor in the progression of drought and in the management of ground water resources to alleviate the impact of drought.

In our day to day activities, we have many uses for water, from individual domestic uses to industrial and agricultural uses. These uses create demand patterns that are highly variable over the course of 12 months.

The South Platte river in Littleton has been reduced to a small stream during the drought of 2002.



Plots of normalized stream-flow in Cherry Creek and residential demand showing the out-of-phase timing of natural surface-water supply with demand. This demonstrates both the need for storage and why many communitities turn to ground-water sources. DATA COURTESY OF PARKER WATER AND SANITATION DISTRICT

For example, the supply/demand curve above illustrates changes in water demand in a residential community in the south Denver metropolitan area. Demand on municipal water begins to increase in the spring with the start-up of landscape irrigation. Peaking in July during the long hot summer days, the demand tapers off with the coming of the typical monsoon rain pattern and shortening days. In contrast, stream flow in Cherry Creek peaks in the spring, and has tapered off before the peak in demand. This "out-of-sync" timing highlights the necessity of water storage projects, such as reservoirs, which capture the peak in runoff to meet the subsequent demand. It also highlights why many communities rely on ground water.

Extended periods of drought wreak havoc on the relationship between supply and demand and challenge the management of water storage to accommodate demand. Meteorological and hydrological drought early in the year suppress the runoff peak forcing water suppliers to rely on carry-over storage from previous years. The situation compounds when the meteorological drought continues into the high demand season, increasing the demand on the supply. This has been the case during the 2002 drought cycle, when the monsoon flow pattern, usually occurring during the peak demand season, arrived late and contained relatively little moisture. In addition, the 2002 drought follows several dry years in some parts of the state.

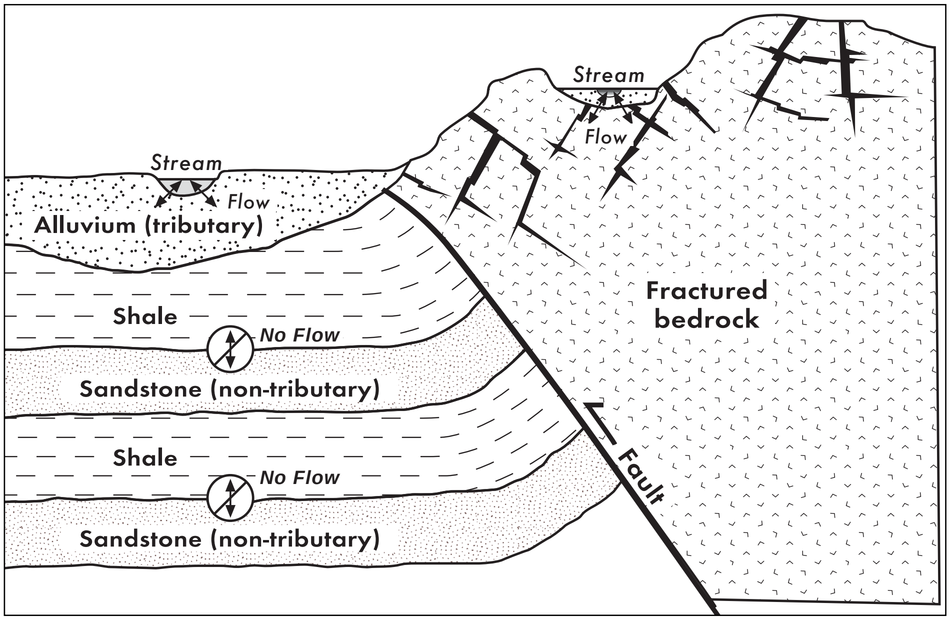
In Colorado, one does not own water, it is considered the state's property. Instead, an individual, or entity, owns the right to use water. Many of the water rights in Colorado are administered by the doctrine of prior-appropriation or, first in time, first in right. The person, or entity, that first puts water to use has the first right to use the water. In times of low water, or hydrological drought, those with the oldest, most **senior**, water rights will continue to be able to use the water, while those with newer, more **junior**, water rights will have to curtail their water usage. The system initially evolved around diversions of surface water by early farmers and miners. As ground-water usage grew, diversions of alluvial ground water were brought into the same system. This aspect of water rights, and water rights administration, plays into how ground water can be used in times of drought.

An overview of the different geologic settings of ground water throughout the state is presented in the first article in this issue of *RockTalk*. In the context of water management and drought, the aquifers that hold ground water can be seen both as a primary source of water as well as components of the water-storage system.

Ground water can be either directly connected to surface water or not connected with surface water at all, depending on geological conditions. This distinction is important to understand, since it affects how the resource is managed. The connection with surface water affects the ability of an aquifer to be recharged, and thus, it affects the sustainability of the resource. Furthermore, Colorado water law has evolved around this distinction with ground water being classified as **tributary** when it is well connected with surface water and **non-tributary** when it is disconnected.

The schematic diagram on the top of the next page shows typical geologic settings of tributary and non-tributary ground water in Colorado. Tributary ground water typically occurs in alluvial aquifers beneath rivers and streams as well as in fractured bedrock aquifers underlying much of the mountain areas. Non-tributary ground water typically occurs in deeply buried sedimentary aquifers where layers of impermeable shale or clay separate the aquifer from tributary aquifers and surface water and where distances to the outcrop of the aquifer are large.

A good example of a tributary alluvial aquifer is the valley-fill aquifer system of the South Platte River and its tributaries. Covering a 4,000 square mile area



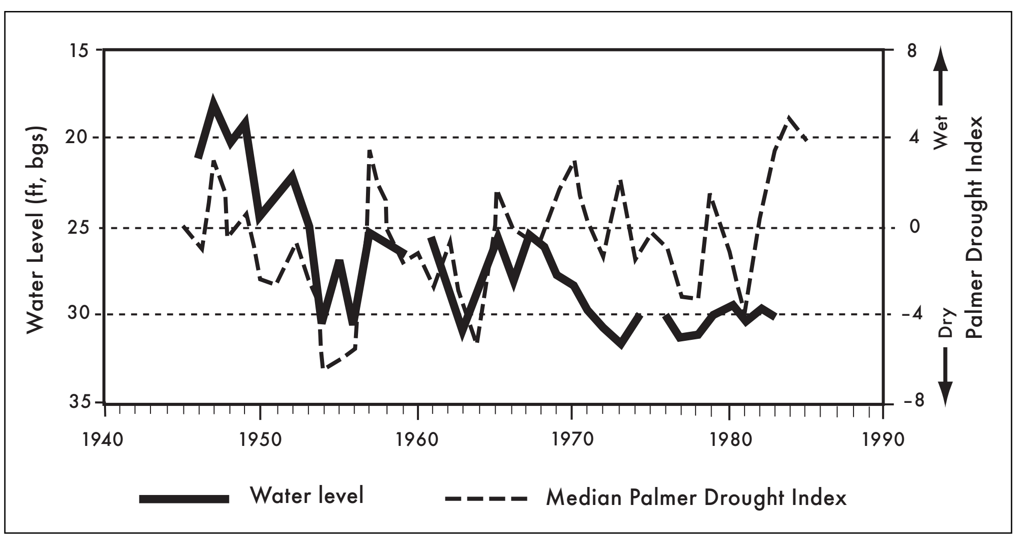
Ground water in alluvial aquifers in the valleys and fractured crystalline bedrock aquifers in the mountains are connected with surface water. In layered sedimentary sequences, the connection between groundwater and surface water may be poor when layers of shale separate the water bearing aquifers from the surface water.

across the northeast corner of the state, this important aquifer holds an estimated 8.3 million acre-feet of water in storage (or 2.7 x 10^{12} gallons). By comparison, there is approximately 1.1 million acre-feet of surface-water storage capacity in the South Platte River watershed.

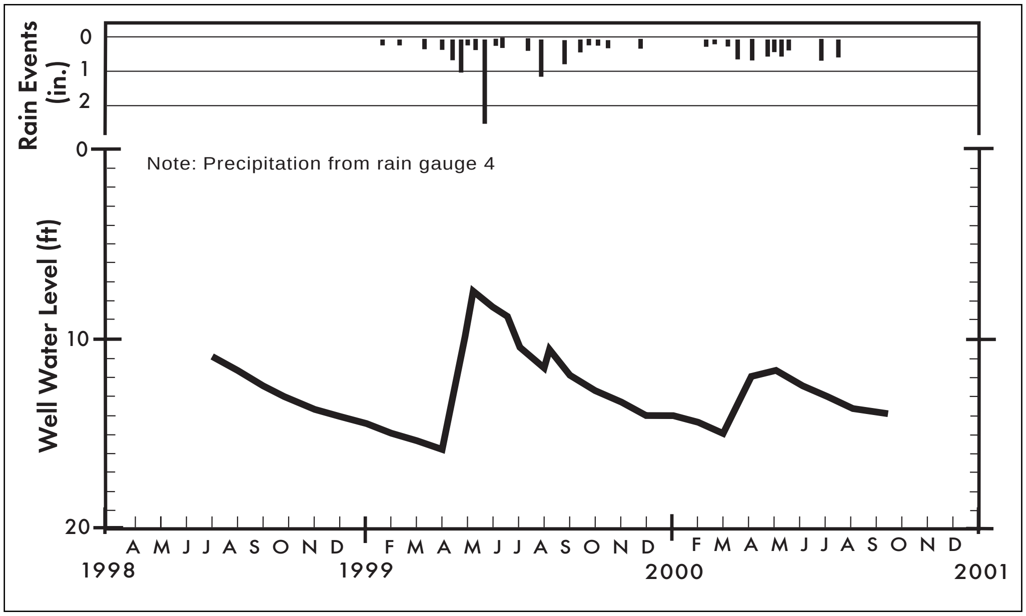
Although there is a tremendous volume of water in storage in the alluvial aquifer system, the groundwater rights are administered along with the surface-water rights. In times of drought, those holding junior water rights may be required to stop pumping their wells when stream flow cannot meet the demands of all owning water rights. This applies to all non-exempt wells that include most large-capacity commercial, municipal, and irrigation wells. Exempt wells that include most household and domestic wells are exempt from this administration process and can continue to pump at permitted rates.

An advantage to tributary water is that, since it is connected to surface water, it is renewable. If a drought cycle results in large depletions of water in storage from a tributary aquifer, that water will be replenished during wetter years. The time that it takes to replenish that water could be several years, depending on how much water was depleted and how fast water enters the system when water is available again.

A hydrograph generated using water levels between 1946 and 1983 from a well tapping the South Platte alluvial aquifer near Greeley is shown below. Water levels at this location declined almost 10 feet between 1945 and 1955. This was a period of time when ground water usage exploded with the installation of many of the large production wells throughout this important agricultural region. Water levels have since leveled off, fluctuating over a five-foot range between 26 and 31 feet below ground surface. Even in times of drought, as indicated by the drought index plot included with the hydrograph, water levels remained in the same range. The relative stability of water levels in this alluvial aquifer during times of drought is due, in part, to the aquifer acting as a reservoir for the stream system. It may also reflect that many of the large capacity wells tapping the aquifer have junior water rights and their use was probably curtailed. The relatively stable water levels during dry periods would have benefited exempt wells.



This hydrograph from a well tapping the South Platte River alluvium near Brighton shows that water levels have been relatively stable, even in times of drought. The drop in water levels between 1945 and 1955 occurred when many of the large-capacity irrigation wells first came on line.



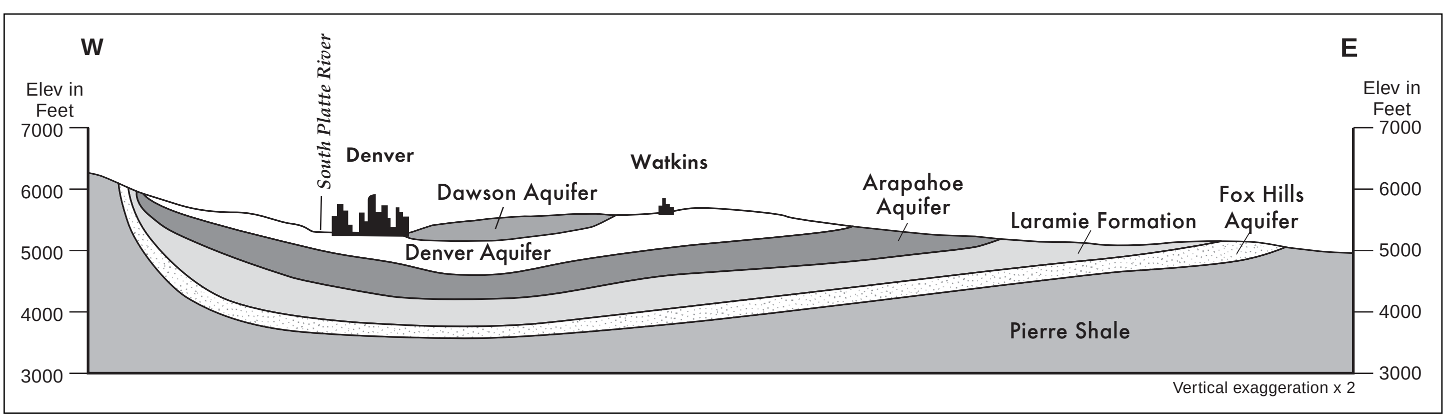
Water levels in an observation well in the Foothills west of Denver respond rapidly to seasonal precipitation events. ADAPTED FROM JEFFERSON COUNTY PHASE I REPORT SUMMARY WATER RESOURCES ASSESSMENT OF THE TURKEY CREEK WATERSHED, 1990–2000

subsequent dry winter-spring cycle will only exacerbate the situation.

Non-tributary ground water paints a different picture. The Denver Basin is a large structural basin underlying nearly 7,000 square miles of eastern Colorado. Consisting of layers of sandstone interbedded with layers of impermeable shale and siltstone, as shown in the cross-section below, the stratigraphy of the basin has been subdivided into the Dawson, Denver, Arapahoe, and Laramie-Fox Hills aquifers. The basin is estimated to hold as much as 270 million acre-feet of water in storage, which is a tremendous volume, compared to the surface water storage in the South Platte River watershed of 1.1 million acre-feet.

The crystalline pre-Cambrian bedrock underlying the foothills just west of the Front Range Metropolitan Area is an example of a fractured bedrock aquifer. Most homeowners in the foothills rely on individual wells tapping this vast aquifer. The hydrograph above, from an observation well near Conifer, shows the immediate connection between the ground water filling the fractures in the bedrock and water at the surface. In spring, the water level in the well rises in response to snow melt and wet spring precipitation, then the water level falls through summer, fall, and winter. The next cycle begins with the next spring. Wells tapping this type of aquifer are very vulnerable to an extended drought period of a dry winter followed by a dry spring, as happened in 2002. In addition, there is little chance of recovery until the following spring, given typical precipitation cycles. A

Much of the ground water in the Denver Basin is considered to be non-tributary due to the separation of the sandstone layers from surface water by shale layers and large horizontal distances to aquifer outcrops. This non-tributary ground water is administered differently than tributary ground water. Instead, holders of non-tributary ground water rights have decrees that specify how much water can be used during a year. This amount depends on land area and aquifer thickness, among other factors. Non-tributary ground water usage will not be curtailed when surface water supplies run short. During a drought cycle, non-tributary ground water can continue to be pumped at the decreed rates when surface water and tributary ground water usage may be curtailed. This gives holders of non-tributary water rights some immunity from



Sandstone aquifers underlie the vast Denver Basin and supply many of the growing suburban communities, particularly in Douglas County, with groundwater. ADAPTED FROM USGS HA-730C.

drought. However, if the drought cycle continues through the high demand period, the increased demands may overwhelm the amount of water available with the non-tributary water rights. In an extended drought, the demands can also overwhelm the physical capacity of the wells and distribution systems.

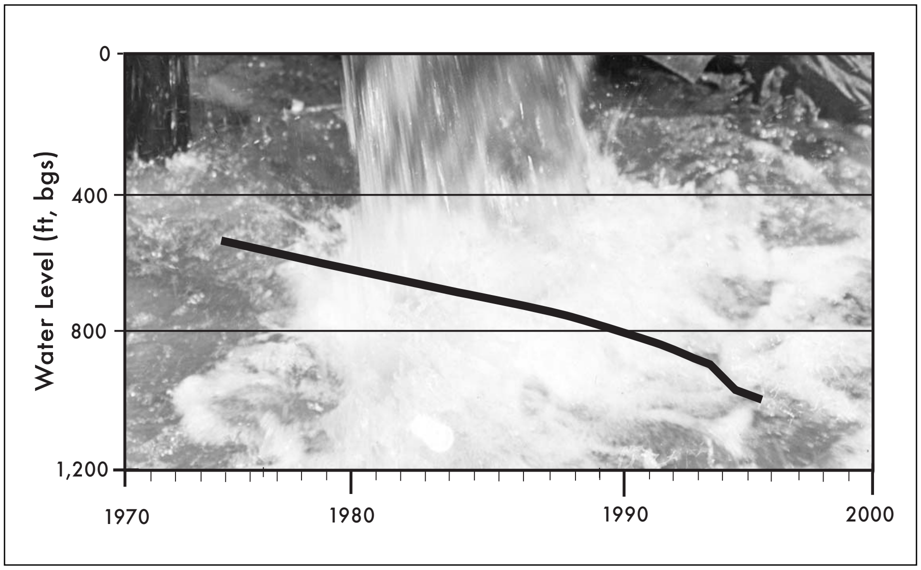
The disadvantage of non-tributary ground water is that, since it is disconnected from surface water, it is not readily replenished. In a sense, non-tributary ground water is not renewable and is being mined. By statute in Colorado, non-tributary water rights allow annual depletions based on a 100-year life of the aquifer, although several local government entities extend this life to 300 years. With the 100-year life of an aquifer, a non-tributary water right holder can pump 1 percent of the total water in storage beneath their property in a year. The net result is that water levels in non-tributary aquifers will decline over time. The decline due to depletions is evident in the hydrograph of a Denver Basin aquifer well shown on this page. Dropping water levels result in lower pump rates and higher pumping costs. Although this non-tributary water source provides a level of immunity from the current drought, in the long-term, it will become more difficult to meet normal demands as it is depleted.

With these factors in mind, how will ground water continue to fit in the water supply picture for Colorado, particularly with respect to drought management? Tributary ground water is inseparable from surface water in the water rights administration system. Most surface water in the state has been spoken for and there is little opportunity for expansion of tributary sources other than through the exchange of existing uses and inter-basin diversions. Examples are changes from agricultural to municipal use and diversions from the west-slope to the east-slope. These exchanges are, at times, quite controversial. Tributary ground water, however, is renewable. On the other hand, there is considerable potential for additional non-tributary ground water supplies, however, this non-tributary ground water is essentially non-renewable and reliance on it does not provide a long-term solution.

The future for ground water lies in how it is managed with surface water. As indicated before, aquifers provide a considerable volume of storage that can be utilized as part of the water management scenario. This storage potential can be utilized in the short-term season-to-season balancing act between natural supply and demand. The storage potential can also be used to provide a cushion for periods of drought. Referred to as conjunctive use, surface water is used as the primary source of water in periods of abundance, while ground water is reserved for use in times of scarcity.

When necessary, ground water recharge can be enhanced to take advantage of peak surface-water flows. Ground water can be recharged directly using surface water, treated wastewater, or treated municipal water. For shallow aquifers, ground water can be recharged through infiltration ponds, spreading basins, or modifications to stream channels to improve infiltration rates. For deeper, non-tributary, aquifers artificial recharge is accomplished with injection wells. The U.S. Bureau of Reclamation recently completed the High Plains States Ground Water Demonstration Program that focused on the artificial recharge potential in a number of geologic settings throughout the High Plains Aquifer region from Texas to North Dakota. Included in this project was an artificial recharge project at a Denver Basin Arapahoe-Aquifer well in southern Arapahoe County. This project confirmed that artificial recharge of the Denver Basin aquifers is technically feasible. Furthermore, the Colorado Division of Water Resources has adopted a set of rules and regulations for the administration of recharge within the Denver Basin. Expect to see increased application of conjunctive use and artificial recharge throughout Colorado as the need for more creative water-supply solutions increases.

—Peter Barkmann



Water levels at an Arapahoe Aquifer well in Douglas County have been dropping at a long-term decline rate of almost 20 feet-per-year in response to increasing ground-water depletions.

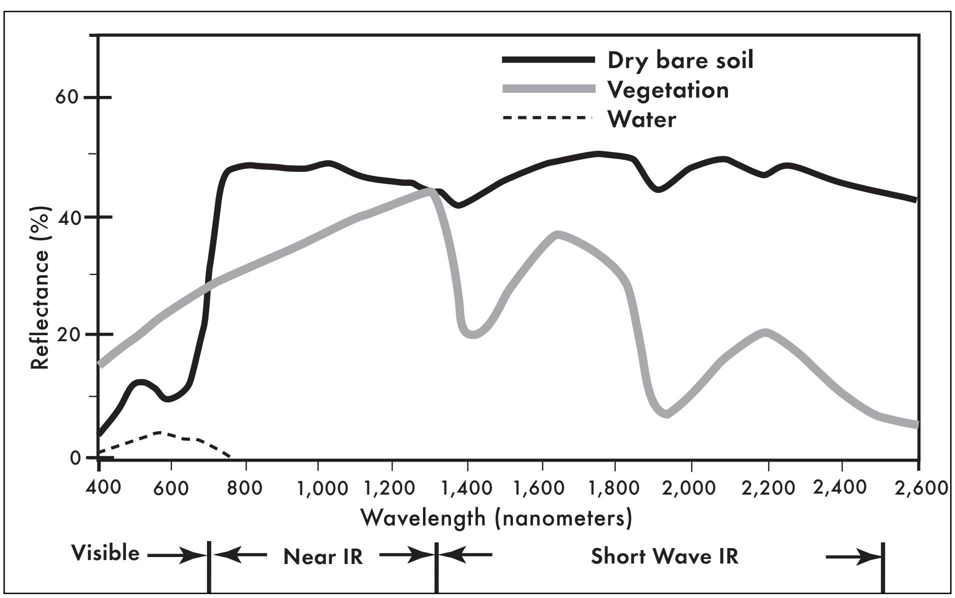
CGS LANDS NASA GRANT

Introduction

The Colorado Geological Survey, along with consulting partners, has recently competed for and won a grant from NASA to apply remote-sensing technology to geology related water-quality impacts in the upper Arkansas River basin. This is CGS's first NASA grant and it highlights the growing use of remote-sensing data in geological applications. The project's formal title is "Determining Contribution of Natural and Anthropogenic Acidic and/or Metalliferous Sources to Contamination of the Upper Arkansas River Watershed" (NASA grant NAG13-02026). Partners on the project are Peters Geosciences, Spectral International, Hendco Services, and the Colorado Mountain College in Leadville.

The project will use hyperspectral remote sensing to identify sources of metals and acidity in selected portions of the watershed in Lake County and northern Chaffee County. Hyperspectral sensors can "see" the mineralogy of exposed rock and identify types of mineralogy that, through interaction with surface runoff and ground water, can adversely affect water quality within a watershed. Both natural and mining-related sources will be examined and related to changes in downstream water quality.

Hyperspectral remote sensing allows specific mineral types to be identified by recording light (i.e. electromagnetic energy) reflected from the Earth's surface. Just as minerals reflect different colors, they also reflect differently in parts of the electromagnetic spectrum beyond the visible range. A hyperspectral sensor records data from the visible (400–700 nanometers, nm), near infrared (700–1300 nm), and short-wave infrared (1300–2500 nm) portions of the electromagnetic spectrum (see graph) in specific wavelengths important in identifying and differentiating minerals. For years, this technology has been used to find mineral deposits for economic development, but its use as a tool in environmental characterization has been more recent.



Typical spectral reflectance curves for vegetation, soil, and water MODIFIED FROM LILLESAND AND KIEFER, 1987

Relation to Earlier Work

The project builds on recent work by CGS (Open-File Report 00-16, future Bulletin 54) that identifies several areas of natural acid rock drainage associated with hydrothermally altered rocks in Colorado, areas that are commonly characterized by acidic streams with high concentrations of metals. Hydrothermal alteration is a process whereby hot water circulating within the earth changes the composition of rocks. Commonly pyrite (iron sulfide) is emplaced in the rocks, which can lead to acid rock drainage (see *RockTalk* Vol. 3, No. 2, April 2000 for a more complete discussion of hydrothermal alteration and acid rock drainage.)

The Grizzly Peak Caldera (Oligocene), one of the areas exhibiting natural acid rock drainage is within the project study area. The caldera lies south of Independence Pass in the headwaters of Lake Creek, a major tributary to the upper Arkansas River. The NASA grant will allow us to look at this area in greater detail and test the usefulness of current remote sensing technology for identification of natural and anthropogenic influences on the environment.

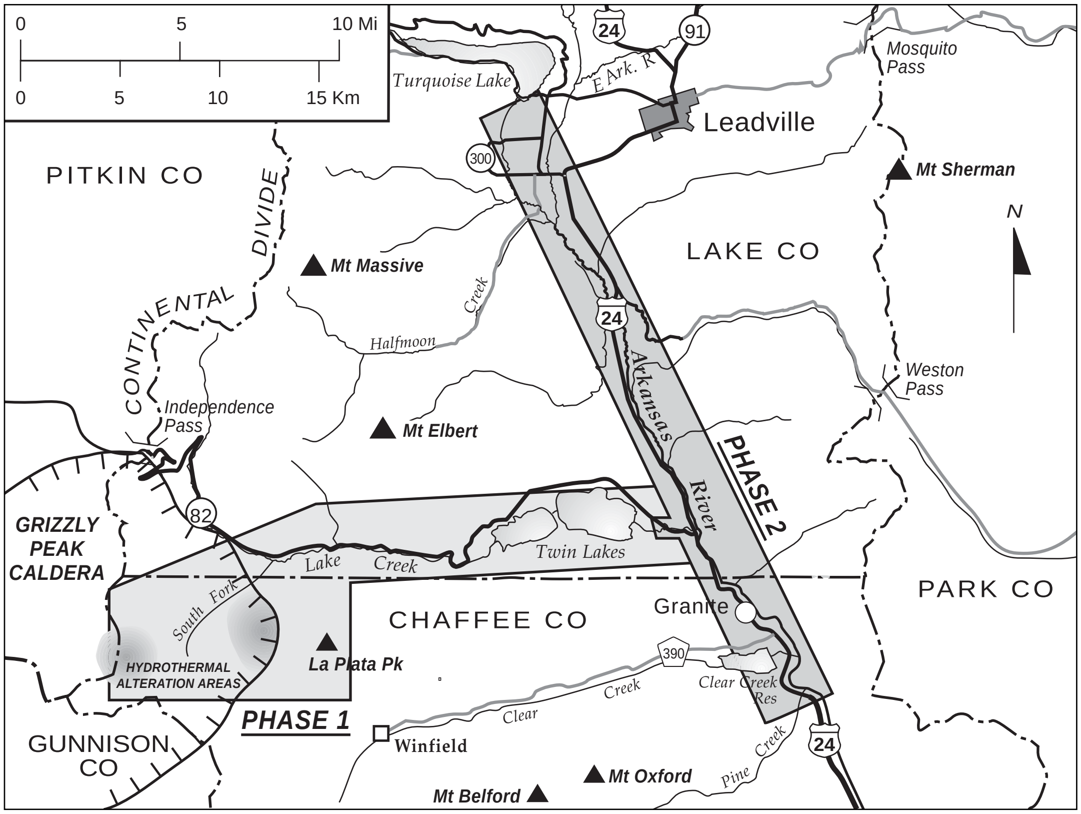


Diagram of the Phase 1 and Phase 2 study areas of the Upper Arkansas River Watershed Project

Project Description

Phase 1 of the project focuses on areas that exhibit natural acid rock drainage, specifically, the South Fork Lake Creek watershed and Lake Creek downstream of the South Fork confluence. The South Fork watershed contains two areas of hydrothermal alteration, Red Mountain (photo) and East Red Mountain, which drain acidic, metal-laden water to Peekaboo Gulch and Sayres Gulch. Metals and acidity derived from these areas affect water quality far downstream in Lake Creek. Before discharging to the Arkansas River, Lake Creek water moves through Twin Lakes Reservoir, which stores trans-basin diversion water for the Colorado Springs water supply. Water sampling will correlate stream water quality to mineral types identified in the alteration areas and downstream. Mineral types will be identified through hyperspectral remote sensing data and "ground-truth" spectral data collected in the field using hand-held spectrometers.

Phase 2 will compare Lake Creek, primarily affected by natural acid rock drainage, with the upper Arkansas River, primarily affected by impacts from historic mining districts in the Leadville area. Much work has been done in identifying, characterizing, and remediating mining-induced contaminants in the Leadville area (USEPA, 2002).

Hydrothermally altered rocks of Red Mountain in the heart of the Grizzly Peak Caldera. Springs here discharge very acidic (pH≈2–5), metal-rich water.

SENSOR TYPES

Name	Description	Spectrum	Platform	Strengths
LANDSAT	Earth resources satellite	VNIR	Satellite	Regional view; low-cost
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer	VNIR & SWIR	Satellite	Monitoring potential; low-cost
IKONOS	Private-sector satellite	VNIR	Satellite	Spatial detail; low-cost
HYPERION	Hyperspectral Imager	VNIR & SWIR	Satellite	Spectral detail; moderate cost
AVIRIS (low-altitude)	Airborne Visible-Infrared Imaging Spectrometer	VNIR & SWIR	Airborne	Spatial & spectral detail
CASI	Compact Airborne Spectrographic Imager	VNIR	Airborne	Spectral detail
SFSI	Short-wave Infrared Full Spectrum Imager	SWIR	Airborne	Spectral detail

VNIR = visible and near infrared; SWIR = short wave infrared

Phase 2 of the project will attempt to use hyperspectral remote sensing to identify sources of metals downstream from Leadville, such as mill tailings transported downstream and deposited in flood plains and point bars of the Arkansas River. Water quality will be analyzed and related to these types of metal sources along the main stem of the upper Arkansas River.

Several kinds of remote sensing data will be used during the project. The sensors used to collect the data vary in spatial resolution, spectral resolution, and cost. Obtaining data from a sensor on a satellite platform is less expensive than from an airborne platform, but the spatial resolution is usually poorer. Various sensors will be used in the project. Several that are likely to be used are outlined in the "Sensor Types" table above.

This is an important project for CGS. Hopefully it will further future application of remote-sensing technology in environmental characterization both within and outside of Colorado and help answer some important questions, such as: can hyperspectral remote sensing help in environmental characterization of both mining and natural sources of metals and acidity to watersheds? What are the geochemical controls on metal solubility and mobility in the South Fork and Lake Creek watersheds? How is water quality in Twin Lakes Reservoir and the Arkansas River affected? How can current sensors be improved to make remote-sensing technology more suitable and cost-effective for this type of application? These are just some of the questions on which this exciting project hopes to shed light.

—Matthew Sares

References

Lillesand, T.M. and Kiefer, R.W., 1987, Remote sensing and image interpretation (2nd ed.): New York, John Wiley and Sons, Inc., 721 p.

http://www.epa.gov/region08/superfund/sites/co/calgulch.html—California Gulch

publications continued from p. 6

Miscellaneous Investigation 20
Ground Water Issues and Answers American Institute of Professional Geologists *$5.00*

Miscellaneous Investigation 70
Colorado Ground-Water Atlas, Colorado Ground-Water Association *$30.00*

Map Series 2
Hydrogeology of St. Charles Mesa, Pueblo County, Colorado *Free in office; $2.00 SH*

Map Series 16
Atlas of Ground Water Quality in Colorado *$12.00*

Open-File Report 00-16
Naturally Degraded Surface Waters Associated with Hydrothermally Altered Terrane in Colorado *$15.00*

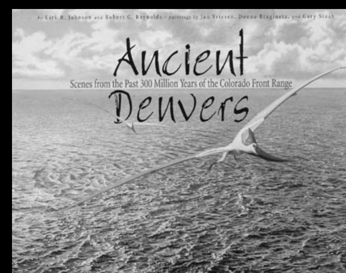
Special Publication 38
Proceedings: Summitville Forum '95 *$95.00*

REVIEW OF ANCIENT DENVERS

The past is illuminated through art in *Ancient Denvers: Scenes from the Past 300 Million Years of the Colorado Front Range*. Based on the Denver Museum of Nature and Science's Denver Basin Project, paleobiological, geologic and hydrologic evidence was compiled on 13 separate formations to bring to life the ancient landscapes of Denver. The museum staff worked closely with area artists to create the most technically accurate renditions of these landscapes from vast seas to lush forests.

While the beauty of these landscapes first captures the reader's attention, the written descriptions of the flora, fauna, and geology will make you bend over backward as an Apatosaurus slowly drifts by. Each formation includes a pictorial and written description along with examples of fossils from the period. A suggested viewing location also gives readers a chance to visit remnants of these ancient worlds themselves.

I thoroughly enjoyed Ancient Denvers and would especially recommend it to people of all ages with an interest in the natural world looking for a beautiful representation of this area's geologic units. Ancient Denvers can be purchased through the Colorado Geological Survey (see ordering information on page 6) or by contacting the Denver Museum of Nature and Science.



—Melissa Ingrisano

Ancient Denvers
K.R. Johnson and
R.G. Raynolds
MI 73____$10.00

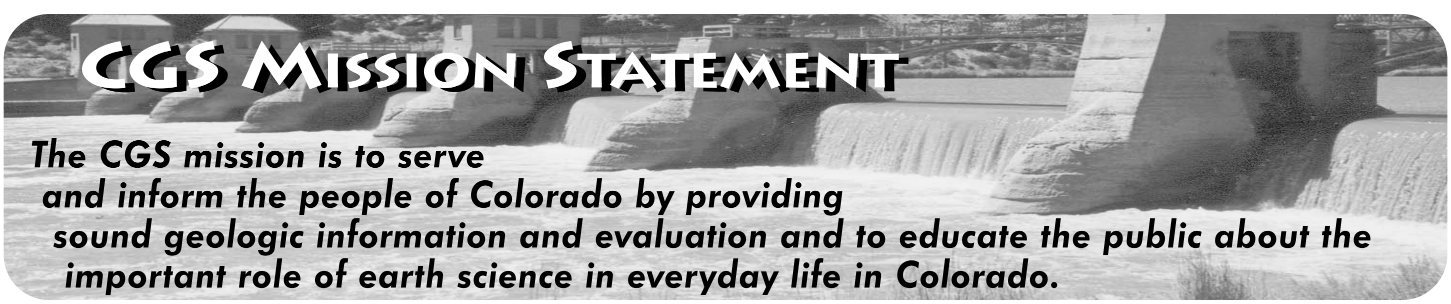
from the director continued from p. 3

important roles in the nature and location of the water. For example, about 20 percent of Colorado's citizens get their water from ground water systems, or aquifers. To understand the nature, extent, location and other important aquifer characteristics like depth, porosity, etc., one needs to understand the nature of the geologic formations serving as the aquifer, as well as the beds around those layers. Protection of water quality of ground-water aquifers is also related to geology, in that if you know where the recharge of the aquifers occurs, you can protect that location so that hazardous or contaminating materials are not placed in or near the recharge areas. It's useful to understand the interaction between rocks and water in terms of surface-water quality as well. There are many activities on the surface that can contaminate a stream—but there are also natural interactions that occur between the water and the rocks it flows over, around and through, that cause metals and acids to move into streams. Knowing about these naturally occurring sources allows society to make better and cost-effective decisions about water treatment.

This issue of *RockTalk* provides an overview of several projects being done by CGS geologists and hydrogeologists that relate to the surface and ground water of Colorado. It's also a good reminder to us all that a simple drink of cool, clear water is actually a geologic phenomenon.

EARTH SCIENCE WEEK —AND WATER

By the time you read this, CGS will have celebrated the fifth annual Earth Science Week, October 13–19, 2002. Each year, Earth Science Week focuses on a different facet of earth science to help all people gain a better understanding and appreciation of the natural world. This year, the theme will be "Water is All Around You" emphasizing the importance of the earth's greatest natural resource. State geological surveys, the U.S. Geological Survey, and many local and professional geological organizations celebrate Earth Science Week each year. You can check out the 2002 activities and learn more about Earth Science Week from the CGS website, or go to the Earth Science Week main web page at the American Geological Institute at: http://www. earthsciweek.org/. Even if this year's Earth Science Week 2002 is over, we'll celebrate it again next year, during the week of October 12–18, 2003.



CGS MISSION STATEMENT

The CGS mission is to serve and inform the people of Colorado by providing sound geologic information and evaluation and to educate the public about the important role of earth science in everyday life in Colorado.

CGS Awards

Congratulations to Lena Martin and Adam Curry, winners of the CGS Special Award for Outstanding Earth Science Project at the Colorado State Science and Engineering Fair April 11–13, 2002. The Fair was held at the Lory Student Center, Colorado State University in Fort Collins.

Outstanding Earth Science Project Awards at the State Science and Engineering Fair

Lena Martin, from Genoa, placed first in the Junior Division with her project, "Time: Sun vs. Clock." Her project used several GPS-surveyed points to determine the accuracy of several sundial designs compared to clock time at different locations near her home.

Adam Curry, of Palisade, placed first in the Senior Division with his project, "The Cosmic Early Warning," which combined electrical theory with an earth-science application. Adam's project used capacitors to measure the differing gravity of the earth to help predict risk associated with earthquake occurrence.

The CGS judging team included TC Wait, Jim Soule, and Peter Barkmann. CGS would like to thank all the students who participated in the Fair.

ROCKTALK

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