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I. INTRODUCTION

The San Luis Valley is the largest intermontane basin in Colorado, comprising about 3,500 sq mi. It includes the entire drainage basin of the Rio Grande River and its tributaries in Colorado. The valley extends from Poncha Pass (near the town of Poncha Springs), in the north, to Antonito, at the New Mexico border, in the south. It extends from the town of Del Norte in the west to La Veta Pass, near the town of Fort Garland, in the east.

The primary aquifers of the San Luis Valley are relatively evenly distributed under much of the valley floor. They are thickest in the east-central part of the valley, in the Hooper - Center area, are thinner near the valley edges, and are nonexistent in the mountainous areas that form the west, north, and east boundaries of the valley.

American Water Development, Inc. (AWDI) applied to the Colorado Division 3 Water Court for a water right for 200,000 acre-feet per year of ground water, most of which would be pumped from the east-central part of the valley. Following 29 days of trial during October-November, 1991, the trial court found against the applicant, in that AWDI's proposed withdrawals would materially injure vested and decreed water rights in the San Luis Valley. As of this writing (May, 1992) the applicant has appealed the trial court's decision to the Colorado Supreme Court.

II. THE GROUND WATER SYSTEM

A. Description of Aquifers

Two principal aquifers underlie the San Luis Valley. Both aquifers are composed of unconsolidated sand and gravel interbedded with silt and clay layers. The shallower of these, called the unconfined aquifer, varies from zero thickness near the valley edges to a maximum of about 200 feet near the towns of Center, Hooper, and Mosca. The deeper aquifer, termed the confined aquifer, extends downward from the top of a series of blue-gray clay layers that separate the two aquifers, to the bottom of the unconsolidated basin-fill sediments. The clay layers are thickest near the center of the basin, becoming thinner and less continuous near the basin margins. At the edges of the San Luis Valley, including most of southern Costilla County, the clays are not present. The aggregate thickness of these clay layers typically ranges from 150 to 250 feet, though there are areas in the east-central valley where the aggregate thickness of the clay beds exceed 1000 feet, and are found at depths exceeding 1500 feet.

The thickness of the confined aquifer basin-fill sediments is not well defined, but it reaches at least 2500 feet in some places, and probably averages over 1500 feet. Recent studies indicate that the deepest economically recoverable ground water in the confined aquifer lies at depths of 2000 to 3000 feet due to indications of poor water quality, reduced hydraulic conductivity, and high well completion and water pumping costs below that depth.

B. Ground Water Recharge and Discharge

Recharge of the major aquifers occurs at the edges of the basin, where runoff of rain and snowmelt in the mountains flows onto the permeable valley sediments and infiltrates to the aquifers. Recharged ground water moves slowly toward the center of the basin and then upward, to discharge at the surface. This discharge ultimately flows into the Rio Grande River and its tributaries or rises into a closed basin called the "sump area," which lies in the east-central portion of the valley between the towns of Mosca and Blanca. In this sump area there is no outlet for surface-water flow from the unconfined aquifer. Evapotranspiration in the San Luis Valley, including the closed basin, is estimated by some researchers to exceed two million acre-feet per year.

In addition to natural ground water discharge, approximately 800,000 acre-feet of ground water are used for irrigation. (An additional 1,200,000 acre-feet per year of surface water from canal diversions is also used for irrigation). Surface diversions and irrigation return flows constitute a major source of recharge to the unconfined aquifer of the valley.

The greatest amount of pumping occurs in the most intensively irrigated area, which is the west-central part of the valley, in the Alamosa - Hooper - Center - Monte Vista area.

About half of this ground water is taken from the deeper aquifer. Some of this ground water from the deeper aquifer recharges the shallower aquifer since not all of the water is used by the crops. Also, there is evidence that artesian pressure is sufficient to cause relatively minor amounts of upward leakage of ground water from the confined aquifer into the unconfined aquifer via leakage through the intervening clay layers. Both of these processes act to raise the water table in the unconfined aquifer in the central portion of the San Luis Valley to within a few feet of ground surface. Several thousand acres of potentially arable land are not in farm production due to waterlogging caused by these processes. The Closed Basin Project currently under way in the sump area is designed to lower the water table, thereby reducing water lost by evapotranspiration.

C. Aquifer and Well Characteristics

Porosity in both major aquifers typically is about 30% and consists entirely of void space between the sand and gravel grains. Because the shallower aquifer is unconfined, wells completed in it do not flow. In the west-central San Luis Valley, production rates from pumping irrigation wells completed in the shallow aquifer range up to 1,000 gallons per minute (gpm). Irrigation wells in the deeper, confined aquifer in the same area typically flow at rates up to 2,000 gpm, with many wells reportedly producing as much as 3,000 to 4,000 gpm. Elsewhere in the valley, wells completed in the unconfined aquifer typically produce an average of 500 gpm, and wells in the confined aquifer typically produce an average of 800 to 1,000 gpm. The volume of economically recoverable ground water in storage in the two major aquifers of the San Luis Valley is estimated to be on the order of 100 million acre-feet, over 75 percent of it in the confined aquifer. An estimated 1800 large-capacity wells in the valley are in the unconfined aquifer, and are less than 300 feet in depth. By contrast, there are an estimated 800 large-capacity irrigation wells (and over 9000 small-capacity irrigation, stock, and domestic wells) which draw water from the confined aquifer. Wells which produce from the confined aquifer range in depth from 300 feet to over 2000 feet.

D. Water Quality

In general, the water quality in the unconfined aquifer and the upper portion of the confined aquifer is acceptable for most agricultural, domestic, and municipal uses. In the unconfined aquifer, ground water usually contains less than 500 milligrams per liter of total dissolved solids (mg/l TDS), with a trend toward better water quality (lower TDS) near the valley edges, and poorer water quality (higher TDS) near the center of the valley. In clay-rich soils near the valley center, there is a moderate to high sodium-hazard potential for irrigation.

In the confined aquifer above a depth of about 2,000 to 3,000 feet (shallower depths near the valley edges, and deeper near the center) the water quality follows the same margin-to-center pattern, with approximately the same TDS concentrations and dominant ions as in the unconfined aquifer. Below 2,000 to 3,000 ft, water quality degrades abruptly to a TDS concentration averaging 3,000 mg/l or greater. Water from below those depths is too salty for most uses without prior treatment.

E. Water Use

Extensive use of ground water in the San Luis Valley dates from the late 1800s, when a large number of low- to moderate-production flowing wells were completed in the upper few hundred feet of the confined aquifer. These wells were used for irrigation and stock watering, as well as for municipal supply. By 1891, there were an estimated 2,000 flowing wells in the valley.

There are presently about 12,000 permitted wells in the San Luis Valley and the surrounding mountainous areas in the Rio Grande drainage of Colorado. Although no exact figures are known, an estimated 5,000 to 6,000 wells are for irrigation, 4,000 to 5,000 are for individual domestic water supplies, about 1,000 to 2,000 are stock wells, and several dozen are municipal wells.

Currently, irrigated agriculture demands about two million acre-feet of water per year, of which an estimated 800,000 acre-feet is ground water. Municipal and individual domestic wells in the San Luis Valley demand an estimated 11,000 acre-feet per year. The Rio Grande Compact, an interstate agreement providing for delivery of Rio Grande River water to New Mexico and Texas, causes an annual demand averaging about 305,000 acre-feet per year. At present, industrial consumption of water in the valley is virtually nil.

II. PHYSICAL BASIS OF AWDI'S NONTRIBUTARY CLAIM

In its amended application filed with the Division 3 Water Court, AWDI sought 117 wells on the Baca Grant and adjacent property in the east-central part of the San Luis Valley and another 15 wells near Villa Grove in the north end of the valley from which 200,000 af/y, in the aggregate, was to be pumped. All wells were to be perforated between 200 and 2500 feet below ground surface, indicating that the water was to be drawn from the confined aquifer. The applicant stated that the source of water was the "San Luis Valley Aquifer", a nonstandard designation.

AWDI contended that the water proposed to be pumped was nontributary, as determined by the effect of the pumping on natural streams. The applicant argued that this impact was to be determined only upon surface flows, and not at all upon hydraulically connected alluvium; that very few streams in the valley were in connection with the aquifer system and, further, that once the streams enter the valley from the surrounding mountains they lose the characteristics by which they are identifiable as natural streams (i.e., that they do not have definite beds, banks, and channels).

AWDI maintained that much of the water to be gained by its pumping would be salvaged evapotranspiration losses by lowering the near-surface water table in the sump area, in a direct comparison to the U.S. Bureau of Reclamation's Closed Basin Project centered a few miles southwest of AWDI's Baca Ranch property:

> "The Closed Basin Project was designed to primarily harvest water lost through evapotranspiration. The Baca Project operates on the same principle." (Baca Project Fact Sheet, American Water Development, Inc., August 20, 1990).

Since the proposed project's wells were to be completed in the confined aquifer below 200 feet, there is an implication of not only regionally-high water table (which is well documented) but strong drawdown effects in the unconfined aquifer due to pumping the confined aquifer.

A third major point propounded by AWDI was that the impact on existing wells would be minimal:

> "Of the 6114 total wells in the San Luis Valley, 5858 (96%) will not be impacted by the Baca Project. Approximately 179 wells will incur higher pumping costs and another 77 wells may be affected to such an extent that they will have to be deepened or replaced with an alternate source of water." (Baca Project Fact Sheet, American Water Development, Inc., August 20, 1990).

These arguments, made by AWDI as the physical framework of its nontributary claim, placed the applicant on a technical razor's edge. On the one hand, AWDI claimed that its pumping would be nontributary, that few streams on the Valley floor were hydraulically connected to the underlying aquifer system (those few which remained, in its opinion, as "natural streams") and that well-interference effects would be minimal. On the other hand, AWDI claimed that a significant amount of its water would derive from salvaged evapotranspiration due to lowering of the regional water table. Of necessity, an application amount ultimately reaching 200,000 af/y would require rigorous attention to technical detail with regard to hydrologic issues. By making its application on the basis of this seemingly contradictory physical framework, however, AWDI made its burden of proof on hydrologic and physical issues even more difficult.

III. PHYSICAL AND HYDROLOGIC ISSUES

A. Hydrologic Role of Faulting

AWDI made the argument that faults, which are prevalent in the geologic materials comprising the San Luis Valley, largely act to enhance vertical connection between aquifer layers in the subsurface. AWDI presented testimony that such faults are prevalent particularly in the Baca Grant area of the valley, and that they serve to provide an avenue of hydraulic connection between the confined aquifer and the unconfined aquifer. The significance of the argument lies in the effect of pumping such a large volume of ground water in a relatively concentrated area. Faults which act as water-movers, that is, enhance the vertical connection, tend to distribute the pumping effect vertically throughout the stack of materials, and to reduce the lateral spread of drawdown or piezometric head decline.

Objectors to the application contended that the action of faults was localized, material-specific and depth-specific. In hard, crystalline or well-cemented rock materials, faulting can induce enhancement of hydraulic conductivity (K), that is, the ease with which water can move through the material. In relatively soft, unconsolidated materials, the objectors pointed out, faulting tends not to enhance K, and may serve to reduce it. Further, the objectors argued in trial that where enhancement of K may exist, it was not as pervasive as the applicant claimed.

B. Depth of "Active/Passive" Interface

On the basis of seismic data, coupled with well-log data from some of the few deep oil and gas test wells in the San Luis Valley, AWDI interpreted that the hydraulic conductivity (K) remained relatively high (i.e. "active" in terms of ground water movement) to about 7000 feet below ground surface in the vicinity of the Baca Grant. The objectors, using many of the same data sources, presented an alternate interpretation in which the hydraulic conductivity beneath most of the valley, including the Baca Grant, decreases significantly below about 2500 feet depth.

As with the faulting issue, the significance of these arguments is that a thicker "active " (high-K) zone would allow more water to be drawn from beneath the Baca wellfield area, and thereby would reduce the lateral spread of drawdown and piezometric head decline.

C. Streams and Hydraulic Connection

Much time and effort during the October-November, 1991, trial of AWDI's nontributary claim was spent by both the applicant and the objectors in arguing the nature of the surface streams in the San Luis Valley. At issue was not only whether the streams were "natural streams" by law, but also whether the streams were in hydraulic connection with the unconfined aquifer.

As discussed above, AWDI contended that most streams were not in hydraulic connection with the unconfined aquifer. The objectors, on the other hand, presented testimony that many of the streams on the floor of the valley were indeed in connection with the unconfined aquifer. Each side presented evidence to support their contentions. In addition, for several major streams including certain reaches of the Rio Grande, the Conejos River, and Saguache Creek, arguments were made concerning the magnitude of streambed conductance. This is a quantity which describes how readily water can be transmitted through a streambed in response to falling or rising water table.

If a stream is not in hydraulic connection with an underlying aquifer, then drawdown due to pumping in that aquifer will not induce greater downward leakage and consequent loss of streamflow. Likewise, a low streambed conductance restricts downward leakage of water, slowing the loss of streamflow.

D. Quantification of Inflow and Outflow

Several parameters related to the quantity of water which flows into and out of the San Luis Valley on an annual basis were at issue during the trial of the nontributary claim. These included evapotranspiration (ET), irrigation consumptive use, and ground-water inflow to the valley from the surrounding mountain ranges. These parameters, particularly the magnitude and distribution of ET, were key to the applicant's argument that approximately 89 percent of its total withdrawal at the end of 100 years of pumping would be due to ET salvage (Findings of Fact, Conclusions of Law, and Decree, Case No. 86CW46, Water Division 3, State of Colorado, February 10, 1992, p. 74).

In addition, each of the inflow and outflow parameters were used by the applicant and the objectors in support of their respective views of the ground water system of the San Luis Valley. These parameters received particular scrutiny in the numerical models entered as evidence in the trial of the nontributary claim.

IV. NUMERICAL MODEL: SCALPEL OR BLUDGEON?

Computerized numerical modeling, used by AWDI to support its claim and by objector State of Colorado in opposition to the claim, makes use of inflow and outflow parameters, streams, aquifer layering, hydraulic conductivity (K) and storativity (S), piezometric head, and historical ground-water withdrawals as a means of simulating an aquifer system by which predictions of pumping effects can be made. A polygonal (often orthogonal) geometric framework of grid cells is constructed, and each cell or node is assigned representative physical parameters.

AWDI used a multi-layer numerical model of the San Luis Valley as the technical centerpiece of its nontributary claim. Likewise, objector State of Colorado constructed its own numerical model of the valley. The applicant and the objectors presented extensive evidence at trial in support of their respective models, and took pains to denigrate the opposing side's model.

Numerical ground water models used as predictive tools, particularly for projects as large as AWDI's, impart unprecedented demands for quality data and technical care to arrive at a valid result. Models are mathematically complex and demand careful calibration, validation, and error-checking. As predictive tools, models are nonunique: more than one model framework or set of values can arrive at a virtually identical distribution of piezometric head or ground-water flow. Models, especially complex ones, therefore demand *significant* investment of funds and effort in data collection and interpretation to make sure that the modeler's concept of a ground water system is as factually reflective of physical reality as possible. Sadly, the nature of predictive models is such that it is easier to use them to support preconceived notions than it is to follow an objective course of data collection, interpretation, model conceptualization, verification, and prediction.

The power and flexibility of numerical models assures that they will continue to be used to assess impacts of water development projects. If models are to be useful tools for prediction, then technical experts, attorneys, managers, and, most importantly, the courts, must begin to understand ground-water modeling in terms of capabilities as well as pitfalls.

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