EVIDENCE SUPPORTING ENHANCED UPWARD GROUND WATER FLOW IN THE SAN LUIS VALLEY, COLORADO

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INTRODUCTION

This study summarizes supporting evidence for the upward flow of ground water in the San Luis Valley (Valley) and suggests this flow may be enhanced along the prominent geologic faults and fault zones in the Valley. The information for this study was obtained from state and federal agencies, private investigators, and university sources. The information included: downhole spinner test data; United States Geological Survey (USGS) technical reports and water resource literature; Colorado Department of Water Resources records and reports; geologic and hydrologic reports by private investigators; reports and theses available from universities; and analyses of pump test data obtained from shallow Closed Basin Project (CBP) wells. Based on the results of this study, further research is suggested for the analysis of aquifer parameters associated with the faults and fault zones, and for the quantitative analysis of upward ground water flow discharged to streams and consumed by evapotranspiration.

BACKGROUND

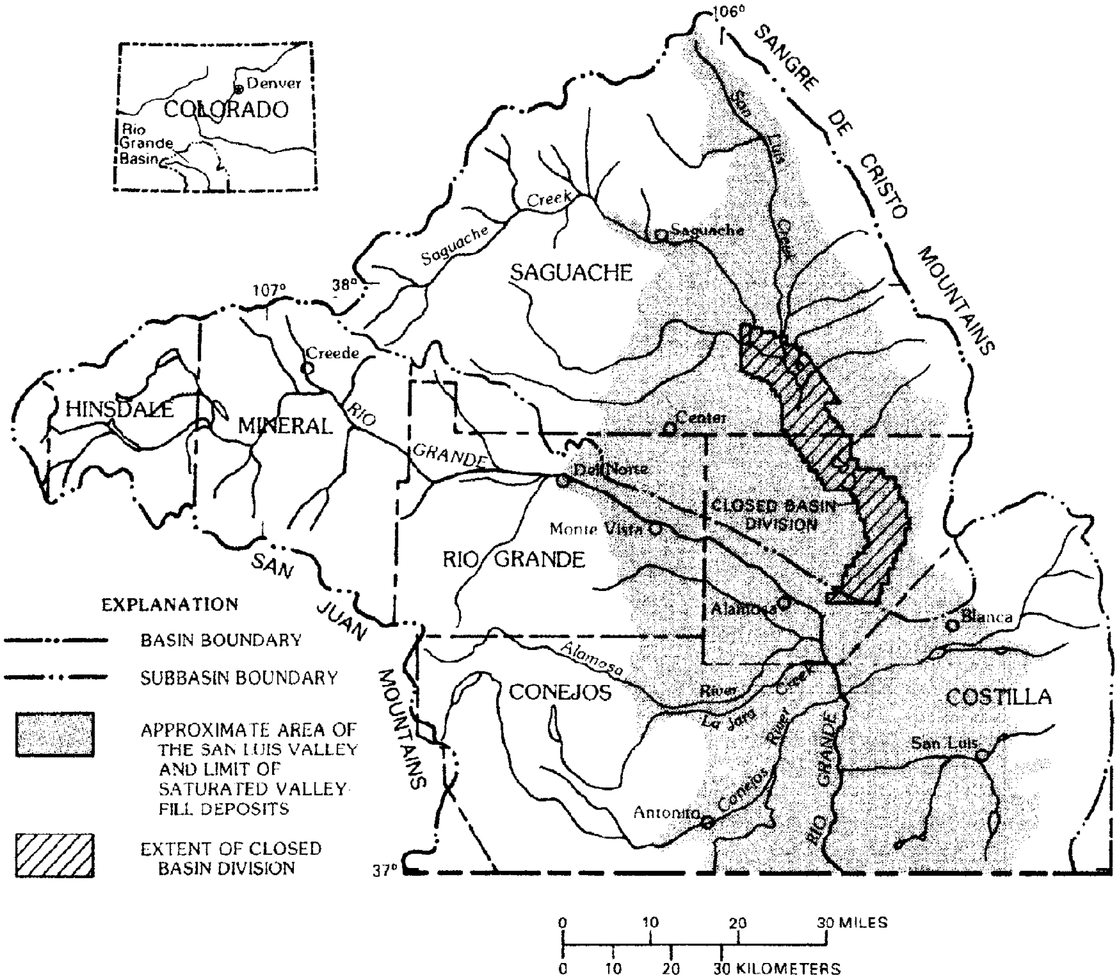
The San Luis Valley (Valley) is an intermontane basin located in south-central Colorado, as shown in Figure 1. The Valley covers an area of approximately 3200 square miles and is bordered by the Sangre de Cristo Mountains on the northeast-east, the San Juan Mountains on the northwest-west, and expands to the south into northern New Mexico, following the Rio Grande Rift structure. The Valley has a complex hydrologic system, including a multi-layered confined aquifer system and a shallow unconfined aquifer system, and numerous surface water features, the largest of which is the Rio Grande. In addition to the natural hydrologic features, the Valley includes many man-made structures (canals, ditches, drains, water wells) used for the extensive development of surface and ground water resources for irrigation purposes. Numerous investigators have completed research on the water resources of the Valley, including detailed studies of the geology and hydrology of the Valley, and as a result, abundant data are available in the public record.

The faulting in the Valley is associated with the structural geologic setting of regional orogenic processes and the Rio Grande Rift. The Valley structure is generally characterized by a horst in the central-valley area, near the town of Alamosa, and grabens along the east and west valley laterals, as shown in Figure 2. Numerous faults have been mapped by the USGS (Tweto, 1979) and identified by analysis of satellite imagery (Earth Satellite Corporation, 1986-1988, and CWRPDA-HRS Water Consultants, Inc., 1987) and interpretation of seismic data (Gries, 1985). The USGS and other investigators have also studied the Valley hydrology in detail by compiling and analyzing surface water and ground water data and modeling the Valley's hydrologic system. These studies have included the analysis of shallow and deep aquifer water levels and the evaluation of the role of faulting in the hydrologic system. These studies and data provide the basis for the general geologic and hydrologic conceptual models of the Valley, shown in Figures 2 and 3, and support the concepts of upward ground water movement in the Valley and enhanced vertical flow along faults and fault zones.

SUPPORTING EVIDENCE

The literature provides abundant evidence of the upward movement of ground water in the Valley. Water levels in wells completed in portions of the confined aquifer have historically indicated upward vertical ground water gradients; many deep wells flow at the land surface (Powell, 1958 and Emery, 1971). High potentiometric surfaces result from the high elevation head of the recharge zones in the San Juan and Sangre de Cristo Mountains and from changes in aquifer parameters in the confined aquifer. More recent research confirmed that evidence exists to support the occurrence of leakage from the confined aquifer upward into the unconfined system (CWRPDA-HRS Water Consultants, Inc., 1987; Harmon and Hanna, 1989; Leonard and Watts, 1989) based on the results of satellite

Figure 1. Location Map of the San Luis Valley and the Closed Basin Division.



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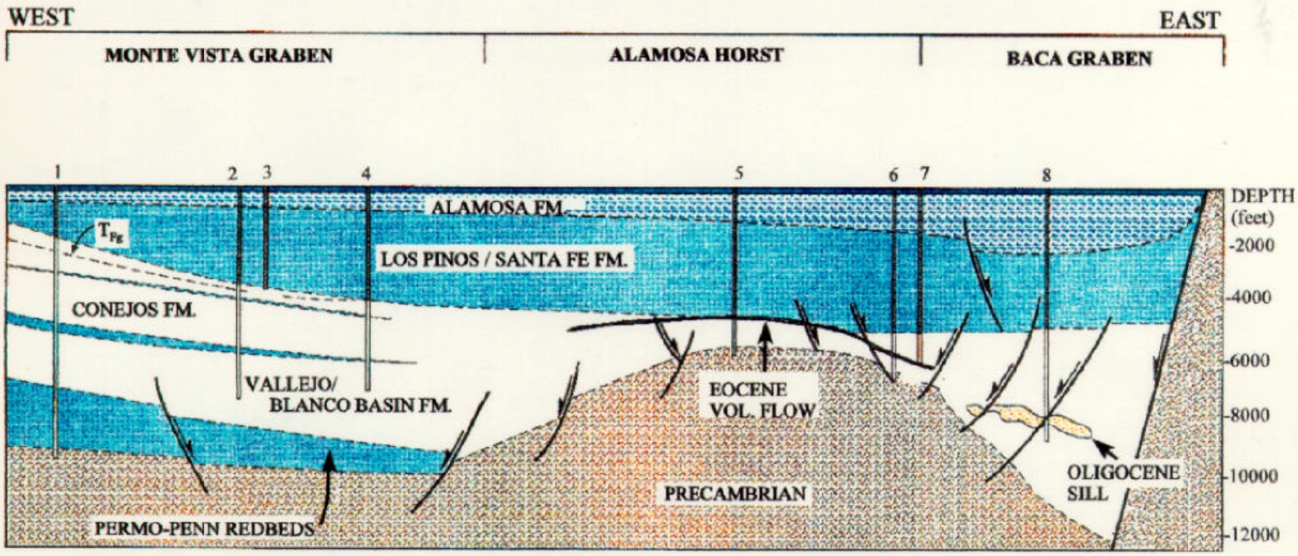
imagery evaluation, water quality analyses, and temperature gradient analyses.

The occurrence of faulting and fault zones in the Valley is also well documented and has been commonly incorporated into computer models of the Valley ground water system. Structural mapping (Tweto, 1979 and Burroughs, 1981) indicates faulting in the Valley, particularly in the central area. Satellite imagery and seismic line data also confirm the presence of faulting and fault zones in the central portion of the Valley (Earth Satellite Corporation, 1986-1988; CWRPDA-HRS Water Consultants, Inc., 1987; Gries, 1985; and Harmon and Hanna, 1989). Figure 4 presents the general locations of faults in the central part of the Valley (Harmon and Hanna, 1989). Recent research on faulting of shallow, unconsolidated materials (Wyatt and others, 1996), confirms the potential for faults to penetrate shallow sediments and potentially act as zones of enhanced ground water flow.

The CWRPDA report included detailed discussion on the enchanced upward flow of ground water along the faults, based primarily on interpretation of satellite imagery, water quality analyses, and the results of a spinner log test. Due to the extensional origin of most of the fault structures, the hydraulic conductivity of the fault plane zone appears to be increased. The water quality data, which indicate deteriorated quality at depth in the confined aquifer, suggest that the water quality of the shallow aquifer is also deteriorated in the vicinity of faults and fault zones due to the enhanced upward leakage of poor quality water from the deep confined aquifer along the fault plan (Giles, 1986). The faults and fault zones act as conduits for vertical flow, and as a result, allow ground water to move more easily upward into the shallow system than in their absence.

Figure 2. Generalized Geologic Cross Section of the San Luis Valley, Colorado



1 - Tennessee Gas 1 - B State; 2 - Orrin Tucker 1 Thomas; 3 - Snowden 1 - Killiam; 4 - W.F. Carr 1 Kennedy-Williams ; 5 -Amerada 1-F State; 6 - Reserve 1 NBH Alamosa; 7 - F.W. Carr 1 Crow; 8 - Mapco-Amoco 1-32 State.

Figure 3. General Hydrologic Flow Patterns in the San Luis Valley

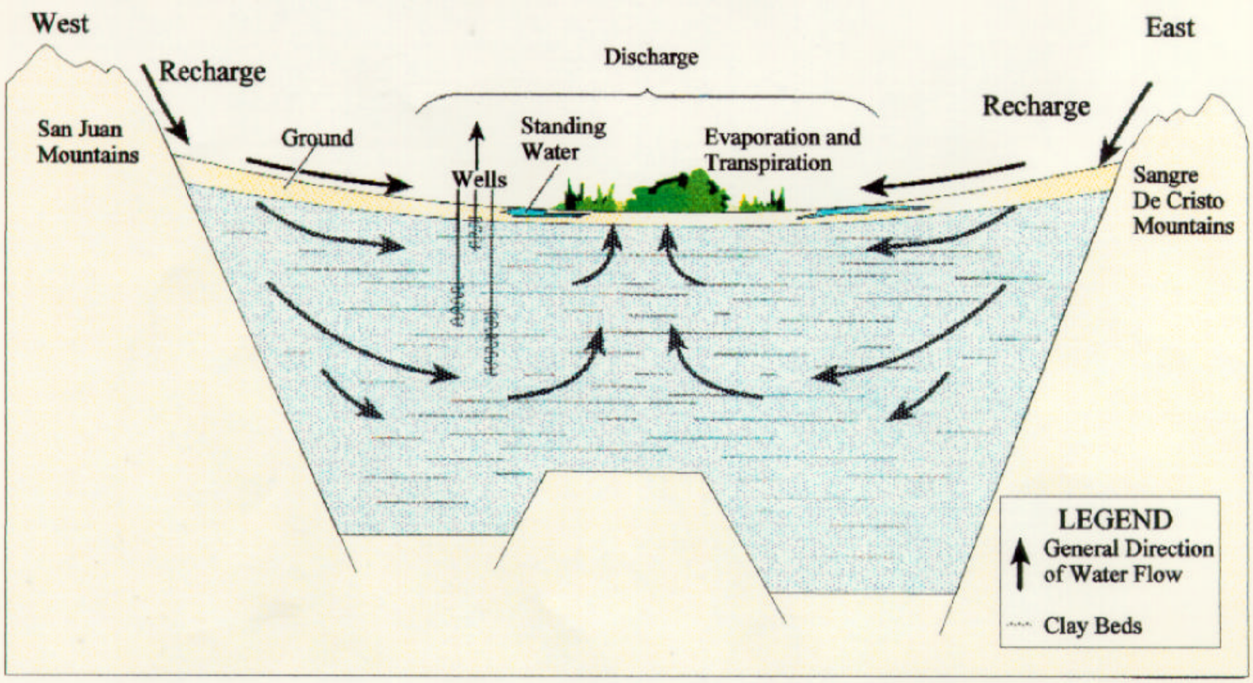
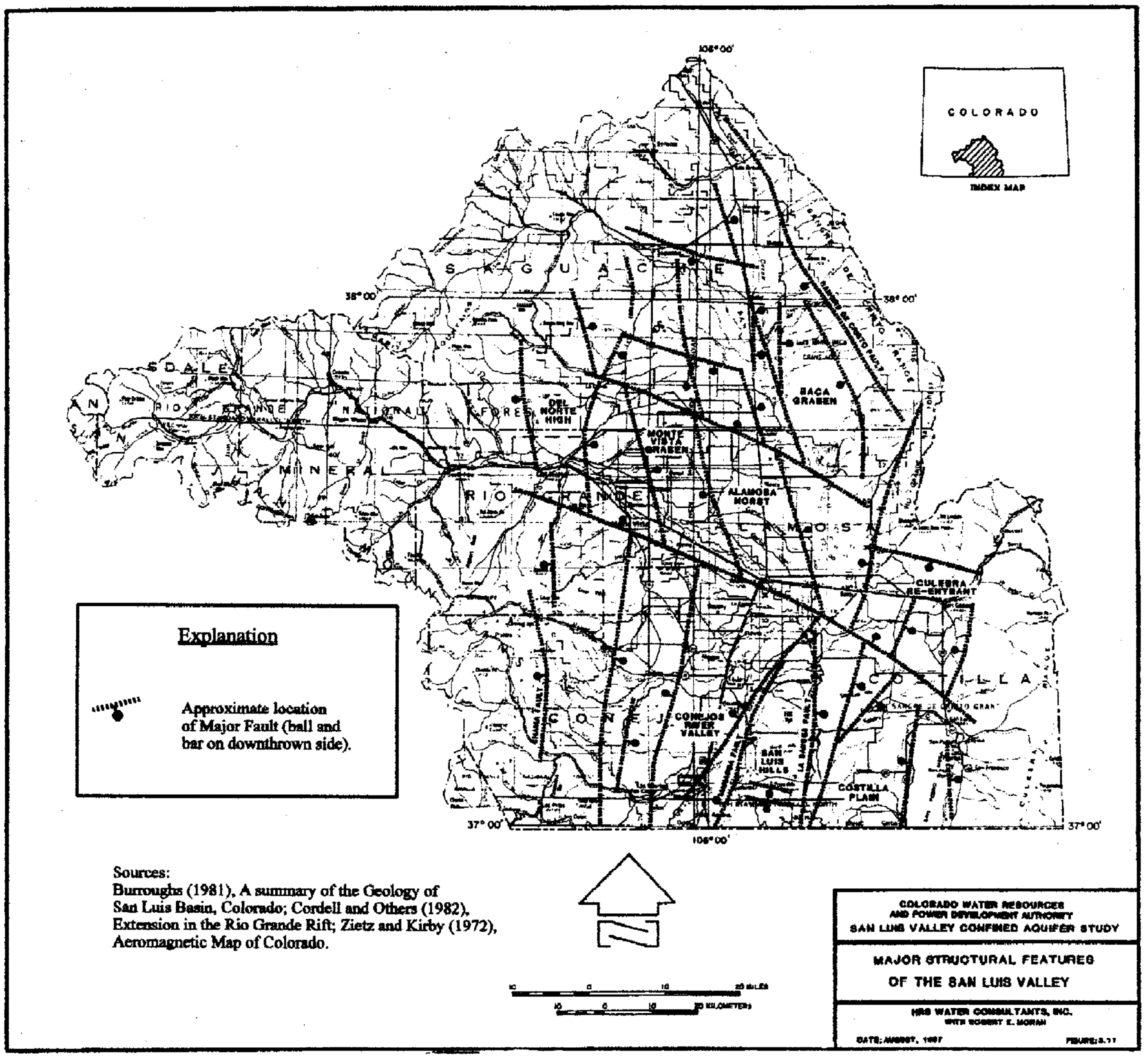
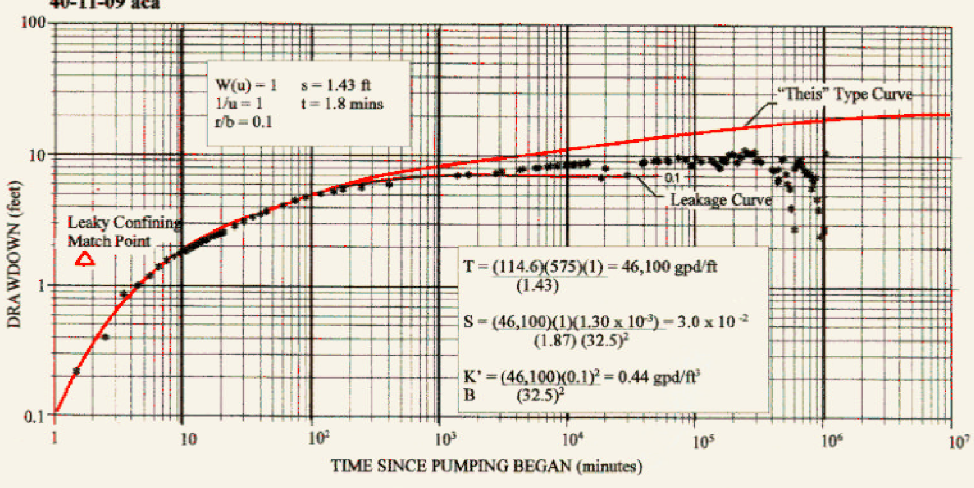


Figure 4. Major Faults of the San Luis Valley



Reprinted courtesy of Colorado Ground Water Association (Hanna and Harmon).

Figure 5. Drawdown vs. Time Plot, 3-Year Test Pumping Well TW3-1, Obs. Well 30W3, LOC. 40-11-09 aca



Analyses of pump test data from 20 CBP wells completed in the shallow unconfined aquifer also support the occurrence of upward leakage and enhanced flow along the fault zones. The data indicate the presence of significant leakage, for which the primary source would be the underlying confined aquifer. This effect is particularly indicated in the data from Well TW3-1, as shown in Figure 5. The test period for this well lasted about three years, and the data reflect the effects of leakage contributing to the aquifer system. The CBP wells are located in a recognized fault zone area and appear to be affected by the enhanced upward flow in the fault zone.

MODEL APPROACHES

The Valley hydrologic system has been modeled numerous times for research purposes (USGS, 1970, 1975, 1988, 1989; Kolm, 1995) and for analysis of water rights cases (Bishop-Brogden Associates, Inc.; Colorado Department of Water Resources, 1991). Most of these efforts modeled faults as conduits for ground water flow with enhanced vertical hydraulic conductivity. Emery (USGS, 1975) modeled a single fault in the vicinity of Manassa, Colorado with the vertical hydraulic conductivity equal to the horizontal conductivity (ratio of 1 to 1), indicating enhanced vertical flow at the fault location. Hearne also modeled faults with increased vertical hydraulic conductivities; with a ratio of horizontal to vertical conductivity of 1 to 1, as summarized in Table 1.

Table 1. Summary of Fault Zone Hydraulic Conductivity Ratios Utilized in Computer Models of the San Luis Valley, Colorado

Model	Fault Zone Horizontal to Vertical Hydraulic Conductivity Ratio
Emery, 1975	1 to 1
Hearne and Others, 1988	1 to 1
Leonard and Watts, 1989	Variable (117 to 1)
BBA, 1991	10 to 1
SEO, 1991	Variable (1 to 10)

The representation of faults as conduits for enhanced vertical ground water flow plays an important role in the modeling results, due to the amount of water available in the confined aquifer system. As a source of water for the shallow system, the upward movement of water impacts the analysis of the quantity of ground water potentially discharged to stream systems and consumed by evapotranspiration.

SUGGESTED RESEARCH

The basis for the aquifer parameters representing the flow conditions of the faulted areas is predominantly inferred from available data. Little data are available to determine the vertical hydraulic conductivity of the faulted areas, due to the small number of deep wells completed in these areas and the lack of control on well completion and testing needed to identify actual movement along a fault plane. The available data from the CBP wells provide limited information for the determination of specific leakage factors, and may be an area for further research, including additional testing and analysis of aquifer properties. Deep well drilling and testing in the fault zones would also provide valuable data for analysis of lithologic samples and the determination of specific aquifer properties, particularly if standard pump testing techniques could be combined with advanced logging techniques.

Investigators have used water balance and model approaches to quantify the probable amount of ground water contributed to the shallow aquifer system due to the upward movement of ground water (Emery, 1975; Zorich-Erker, 1980; Huntley, 1976). Based on the available data, the water balance approach is probably the most reliable, but the least specific for flow along an actual fault plane. The water balance analyses can continue to be refined using new data on stream flows, evapotranspiration potential, and further analysis of the amount of ground water inflows contributed from the San Juan Mountain recharge area.

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