VII. Overview of the Rio Grande Decision Support System

148. The specific study mandated by HB 98-1011 and carried out by the State Engineer and Colorado Water Conservation Board, culminating in the Rio Grande Decision Support System, is referred to as the RGDSS Study. The Court finds that the RGDSS Study meets HB 98-1011's requirements for a specific study of the Confined Aquifer System.

149. The RGDSS can generally be described as "an interactive computer-based system that utilizes data and computer models to help decision makers solve unstructured problems." *Transcript (Bennett) Vol. XIII* at p. 2537. This is not the State of Colorado's first decision support system. It has previously developed a decision support system for the Colorado River Basin and is in the process of developing one for the South Platte River Basin. State's Exhibit 8, *C.R.C.P. 26(a)(2) Disclosure of Ray B. Bennett, P.E.,* at p. 1. A graphic representation of the elements of a decision support system is found in Figure 1.2 from State Exhibit 8, reproduced below on page 54. The foundation of the decision support system is the relational database shared by all the components. The database is designed to incorporate new data accumulated over time.

150. Five principle contractors were involved in the development of the RGDSS Study. *Transcript (Bennett) Vol. XIV* at pp. 2560– 2570. The primary groundwater contractor was HRS Water Consultants Inc. HRS undertook an extensive review of all available geologic and hydrologic data for the San Luis Valley; built an extensive groundwater database containing groundwater levels, pumping measurements, pump test data, aquifer characteristics, geophysical data, and other information; studied the major water budget components of the groundwater system; developed a revised hydrogeologic conceptual model of the San Luis Valley; and did the initial development of the RGDSS groundwater model to simulate the occurrence and movement of groundwater in the San Luis Valley's aquifers. *Transcript (Harmon) Vol. II* at p. 258-261. The work of HRS and the RGDSS groundwater model are discussed in greater detail below.

151. Determination of consumptive uses of water in the San Luis Valley was a necessary part of the RGDSS Study. The consumptive-use study was performed by Leonard Rice Engineers, Inc., and their prime subcontractor, Agro Engineering, Inc. They studied and mapped the irrigated lands in the San Luis Valley, the types of crops grown, the irrigation water supplies, irrigation methods and prepared a report estimating the amount of consumptive use of water by irrigated agriculture and the amount of water pumped for irrigation purposes. See generally *Transcript (Thompson), Vol. VI.*

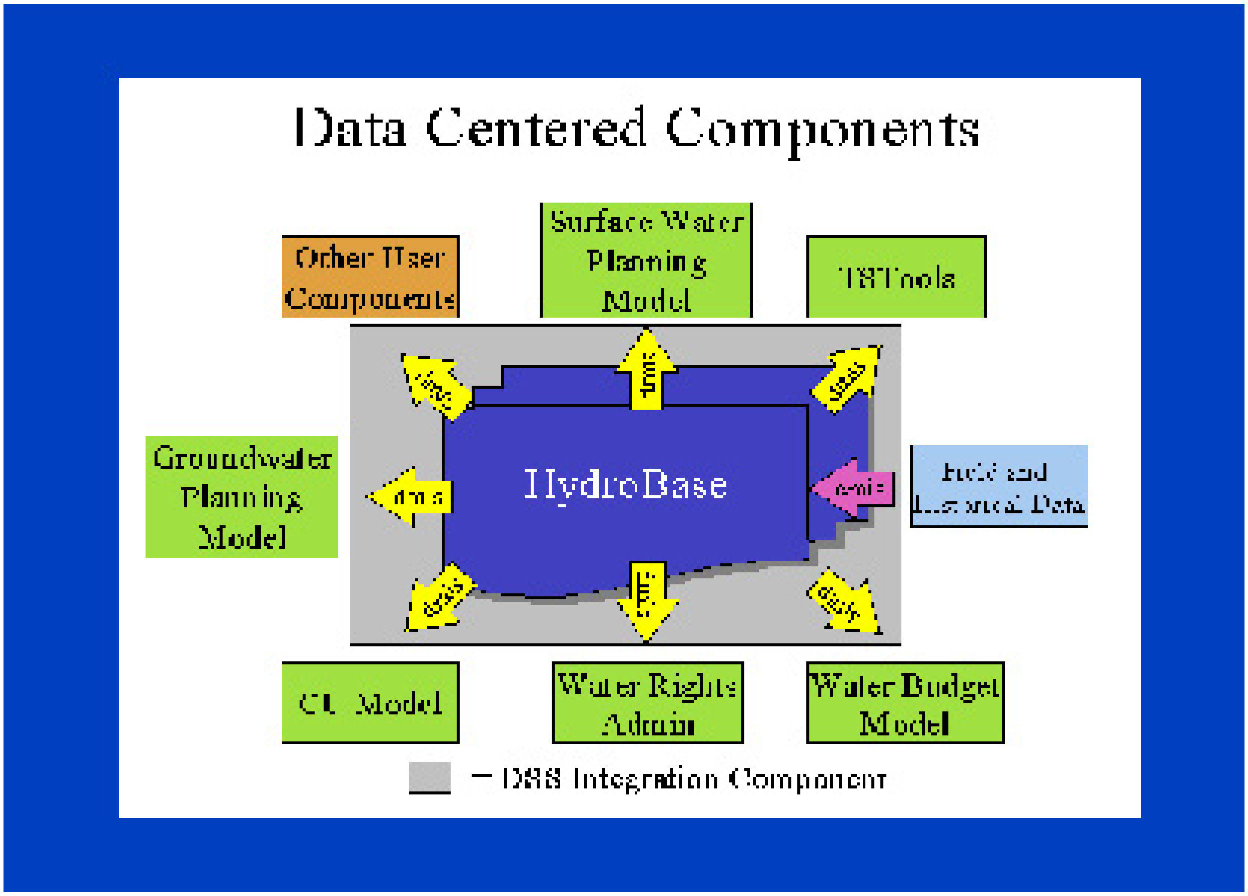
152. A study of the surface water supplies and their interaction with the groundwater system was also necessary, and that study was performed by Hydrosphere Resources Consulting. Hydrosphere studied and collected data concerning the surface water system of the San Luis Valley, including all major ditch systems, major reservoirs, and stream flows. Hydrosphere then developed a computer model of the surface water system, which includes the interrelationship between the ground and surface water.

153. Extensive software development was also required to operate much of the RGDSS. This work was performed by Riverside Technology. The work included, for example, the data management interfaces that allow different tools within the RGDSS to communicate with the central database. *Transcript (Bennett) Vol. XIV* at p. 2573, ln. 4 – 11. The RGDSS also makes extensive use of geographic information systems (GIS) to spatially locate and portray data. This GIS work was performed by HDR who integrated the numerous geographic coverages necessary for the other RGDSS elements. The GIS data includes such things as roads, counties, water districts, hydrologic boundaries, stream gages, climate stations, ditches, canals, wells, and drains.

154. Throughout the RGDSS Study results of the work were documented with "task memoranda." *Transcript (Bennett) Vol. XIII* at p. 2572, ln. 13 – p. 2573, ln. 3. The majority of these task memoranda and the RGDSS data are available to the general public through a State website at http://cdss.state.co.us/dnn/riogrande/tabid/57/default.aspx.

155. The completed RGDSS consists of an extensive central database and a number of "tools" that are independent of the database, but freely communicate with the database through a data management interface. Data in the central database includes water rights information, climatological and hydrographic data, agricultural data, groundwater data, and other observed data. The "tools" related to this database include: the RGDSS groundwater model; a surface water planning model; a consumptive-use model (used to determine the consumptive use of water by irrigated agriculture); a water budget model, and a water rights administration model. *Transcript (Bennett) Vol. XIV* at p. 2617, ln. 21 – 2620, ln 2; see also State's Exhibit 8 at p. 3, Fig. 1.2. The water rights administration model is not currently a tool designed to make day-to-day decisions about water rights administration. Rather, its major function is the ability to provide real time stream flow information to the Water Commissioner. *Transcript (Bennett) Vol. XV* at p. 2820, ln.14 – p. 2821, ln. 11. State Exhibit 8, Figure 1.2 appears below.

Figure 1.2 Data Centered System



VIII. Salient Points of the RGDSS Study

156. In what follows the Court will summarize the results of those portions of the RGDSS Study most pertinent to the issues in this case.

A. Hydrogeology of the San Luis Valley

157. A significant part of the RGDSS Study carried out by the State was a thorough study of hydrogeology of the San Luis Valley which formed the basis of the RGDSS groundwater model. This work entailed reviewing and analyzing all available hydrogeologic data on the San Luis Valley, the acquisition and analysis of new hydrogeologic data in the San Luis Valley, interpreting and analyzing the data to form an up-to-date understanding of the stratigraphy and the subsurface geologic relationships in the San Luis Valley, and then developing a conceptual model of the hydrogeologic framework of the San Luis Valley. This work was performed by and under the direction of the Proponents' expert witness Eric J. Harmon of HRS Consultants, Inc. *Transcript (Harmon) Vol. II* at p. 253.

158. Mr. Eric Harmon was qualified as an expert in geology, hydrogeology (including aquifer testing, design and implementation), the analysis of data from aquifer tests, geophysical investigations and interpretation of the results of such investigations, and in establishing the hydrogeologic framework for computer models. Mr. Harmon has worked in the San Luis Valley on various water and geological issues since 1979. This work has been for both public and private entities and included various areas of the Valley. His knowledge of the hydrogeology of the San Luis Valley is extensive, detailed and informed by the many years he has worked studying the Valley and his participation in the peer review of the RGDSS groundwater model.

159. Mr. Harmon's testimony was largely undisputed with the exception of his opinion concerning the potential for land subsidence and the effect of artesian pressure declines on stream flows and aquifer recharge patterns. Because the hydrogeology of the San Luis Valley is central to many of the disputed issues in this case, the Court will review this evidence in some detail. Much of this evidence is drawn directly from the testimony of Mr. Harmon and is also summarized in State's Exhibit No. 12, *Colo. R. Civ. P. 26(a)(2) Disclosure of Eric J Harmon, P.E.,* and State's Exhibit No. 127, *Rebuttal to Lytle Water Solutions, LLC Expert Report in Case No. 04CW24.*

160. Mr. Harmon's firm developed the hydrogeologic framework for the groundwater model, and he characterized his own role as manager of the groundwater component of the RGDSS. Mr. Harmon served on the peer review committee for the RGDSS groundwater model and had frequent interaction with the mathematical modeler, Dr. Schreüder. Importantly, he recommended early on that the State's prior groundwater model was inadequate for the RGDSS and that a new model based upon the MODFLOW mathematical framework should be constructed. *Transcript (Harmon) Vol. II* at p. 326.

161. The RGDSS and its many contributors, including Mr. Harmon, drew upon the earlier familiar studies. This includes the 1910 Siebenthal Report[18] the Rio Grande Joint Investigation,[19] the Powell Report,[20] and of course, the work of Phillip Emery.[21] In some instances the RGDSS confirmed and improved earlier impressions. In other respects, the RGDSS accumulated new information and provided a much clearer and more detailed picture of the hydrogeology of the San Luis Valley. In a few instances, the RGDSS calls into question and refutes some earlier understandings.

162. In analyzing the RGDDS, the RGDSS groundwater model and the protests presented to the Rules, the Court recalls the observation of Sören Kierkegaard that "Life can only be understood backwards; but it must be lived forwards." The RGDSS Study provides less than a complete picture of the hydrogeology of the San Luis Valley but it provides this Court with immensely more information and a better understanding of the interplay of the aquifers and

[18] C.E. Siebenthal, *Geology and Water Resources of the Rio Grande*, U.S.G.S. WSP 240 (1910), State Exhibit 38.01

[19] *Rio Grande Joint Investigation in the Upper Rio Grande Basin 1936-37,* National Resource Committee (1938), State Exhibit 39

[20] William J. Powell, *Groundwater Resources of the San Luis Valley, Colorado* U.S.G.S WSP 1379 (1958) State Exhibit 40

[21] Phillip A. Emery, Robert J. Snipes, John M. Dumeyer, John M. Klein, *Water in the San Luis Valley, South-Central Colorado* USGS, Colorado Water Resources Circular 18 (1973)

surface streams than available to anyone in the past. We must base our judgments on what we do know. One of the things we know is that our knowledge is limited and therefore that science may lead us in new directions in the future. Humility in the face of the unknown cautions the Court to be conservative. However, the leaps forward in our knowledge as a result of the RGDSS Study should not be underestimated. While perhaps not entirely fair, a comparison of the map of the San Luis Valley attached to the opinion in the Supreme Court in *Alamosa-La Jara v. Gould,* 674 P.2d 914 (Colo. 1984) as Appendix A to the map of San Luis Valley attached to this opinion as Appendix B underscores the attention to detail that has marked the development of the RGDSS Study and the RGDSS groundwater model.

1. Formation of the San Luis Valley

163. Eric Harmon described in great detail the formation of the San Luis Valley. See *Transcript (Harmon) Vol. II* at p. 312-342. A brief accounting of the formation helps us understand the complexity of the hydrogeology and the difficulty that complexity poses for development of the groundwater model. Illustrative Exhibits 107 through 111 assist in understanding his testimony summarized briefly here. The San Luis Valley is part of the Rio Grande Rift, a continental-scale structure which extends from the Upper Arkansas Valley through the San Luis Valley and extending south through New Mexico and into Chihuahua, Mexico. The San Luis Valley is unique in that it is the only true rift valley in Colorado. Rift valleys are formed by extensional forces that pull apart the earth's crustal sediments in a roughly east-west direction. 65 million years ago, at the beginning of the Paleocene Era, the "Valley" was actually a highland sitting on ancient granite-type rock that is now still found at great depth in the Valley floor and which can be seen in the Sangre de Cristo Range.

164. The deepest formations in the Valley were deposited before rifting began, in the Oligocene Epoch approximately 35 million years ago. Most pre-rift formations in the Valley are now located at great depth and are too compressed and consolidated to be of importance as aquifers. The majority of the sediments and volcanic rocks that are important as aquifers were deposited at the same time that the Valley was forming, between 35 million years ago and the present. Many of the hydrologically important layers were deposited due to the formation (rifting) of the Valley and the uplift of the Sangre de Cristo Mountains to the east and the San Juan Mountains to the west. The uplift of the Rocky Mountains was just beginning during this time period. During the Paleocene and Eocene Eras, there was a downdrop of an early basin which is recognized as the Blanco Basin Formation. This formation is composed largely of sandstones and shaley sandstones. *Transcript (Harmon) Vol. II* at p. 314. At the end of the Eocene Era, 35 million years ago there was still nothing resembling the current San Luis Valley but the general uplift of the Rocky Mountains was in progress. During the Oligocene Era, from 35 to 23 million years ago, the San Juan Mountains were formed by a tremendous and complex outpouring of volcanic rock and ash which included many caldera explosions estimated to be 15,000 to 20,000 times the volume of the Mount St Helens' eruption. *Transcript (Harmon) Vol. II* at p. 316. The entire area we would now call the floor of the Valley was covered with volcanic material thick in the west and thin in the east. Today, people identify a prominent volcano, the Summer Coon Volcano, just north of Del Norte. The volcanic nature of the rock is evident running north through the La Garita Hills, Cochetopa Hills all the way to Bonanza. *Transcript (Harmon) Vol. II* at p. 317-19. In addition, there was faulting taking place in this overall

formation known by the geologists as the Conejos Formation. Faulting increases hydraulic conductivity. *Transcript (Harmon) Vol. II* at p. 320.

165. "A rift is actually a fault-bounded valley where the sides of the valley either remain stable or are uplifted and what becomes a valley is a downdropped block." *Transcript (Harmon) Vol. II* at p. 323. Around 27 million years ago, tension was pulling the crust of the earth apart in this area and it resulted in major faulting on the eastern side of what is now the San Luis Valley with the consequent rise of the Sangre de Cristo Mountains and the lowering of the eastern portion of the Valley. At the same time, there was continued volcanic activity in the San Juan Mountains. These two occurrences resulted in substantial new deposits of sediments including rock material from the uplifted Sangre de Cristo Range and basalt-type sediment from the volcanic activity. From the period 27 million years ago to around 5 million years ago these sediments accumulated into what geologists have identified as the Santa Fe Formation of "interbedded sandstones, conglomerates, clay stones and some shale." *Transcript (Harmon) Vol. II* at p. 324-25. In the western part of the San Luis Valley, a downdrop occurred which appears in the exhibits as the Monte Vista Graben and a new uplift occurred in the central part of the Valley which appears in the various documents and exhibits as the Alamosa Horst. The San Luis Hills are a surface expression of the horst. Then a new graben developed on the eastern side of the Valley which filled with new sediments. This is the Baca Graben which overlies the other deposits in the eastern part of the Valley.

166. Beginning in the Pliocene Era as illustrated in Exhibit 111, new volcanic activity in the form of flood basalts in the Costilla area blocked the flow of water out of the San Luis Valley at the San Luis Hills creating a giant lake known as Lake Alamosa which covered the portion of the San Luis Valley we now refer to as the "Closed Basin" area for millions of years. The flood basalts thicken as you move south from the San Luis Hills and are a dominant characteristic of the Costilla area and significantly differentiate it from the other portions of the Valley. The thick flood basalt can be easily observed at the Rio Grande Gorge by Taos. This formation is known as the Servilleta Formation, presumably because it folds out across Costilla and Taos counties like a napkin. *Transcript (Harmon) Vol. II* at p. 327-29. The lake and marshes held quiet water and created great thicknesses of interbedded clays and sands from the combined marsh and lake and continued rifting.

167. Of course, at some point, by erosion, the Rio Grande broke through the volcanic barrier, and gravity carried the waters south creating the Rio Grande Gorge and the river we know today. With the end of the lake, the depositing of clay ceased but new sediments arrived in the form of sand and gravel deposition which is alluvial in nature and is thickest on the edges of the San Luis Valley and thinnest in the center. These sands and gravels are as thick as 500 feet on the western foothills and 50-60 feet in the center of the Closed Basin with an average thickness of approximately 100 feet. This layer corresponds to what is called the "unconfined aquifer." It is noted for its high conductivity and thus moves groundwater quite readily. *Transcript (Harmon) Vol. II* at p. 336-38. These interbedded layers of sand and clay are the Alamosa Formation. The clay is soft and porous, with porosity as high as 50%. *Transcript (Harmon) Vol. II* at p. 333. The interbedded clays and sands of the Alamosa Formation are referenced in this case and this opinion as the "blue clay series" and the sands between and beneath the blue clay layers hold considerable water that is under artesian pressure. *Transcript (Harmon) Vol. II* at p. 340-41. While there are deeper waters also under pressure below the clay layers, these clays are critical

to understanding the arguments for and against the proposed Rules. With this brief explanation of the geologic history of the San Luis Valley, we turn to a description of its current geology.

2. Geologic Layers

168. Eric Harmon prepared a detailed description of the geologic layers in the San Luis Valley as part of the conceptual framework in the RGDSS, and these descriptions are incorporated into the groundwater model. The San Luis Valley contains a series of geologic layers with distinctive lithologic characteristics, and which together comprise an interconnected system of aquifers. The aquifers are composed of water-saturated sediments, sedimentary rocks, and volcanic rocks. The shallow aquifer, the unconfined aquifer, is composed primarily of sand and gravel. The deeper aquifer, the confined aquifer, is composed of several water-saturated layers that can be identified by their different lithology and hydrologic characteristics. While the layers of the confined aquifer have distinct lithologies and aquifer characteristics, the evidence shows that the layers are hydraulically connected to each other, to the overlying unconfined aquifer, and to the surface streams.

169. The geology of the San Luis Valley is complex, and most of the hydrogeologically important layers do not extend across the entirety of the Valley. Thus, to understand the Valley's geologic structures and their hydrologic functioning, the RGDSS documentation describes this layering by reference to distinct geographic regions of the Valley as well as vertical layers. The generally distinct geographic regions of the San Luis Valley are as follows:

> **Northern San Luis Valley**: the portion of the Valley that lies north of both the Rio Grande and Costilla County, and which is commonly referred to as the Closed Basin. In the Rio Grande Compact, the Closed Basin is defined as that part of the Rio Grande Basin in Colorado where the streams drain to the San Luis Lakes and adjacent territory, and do not normally contribute to the flow of the Rio Grande.
>
> **Conejos and Alamosa River Valleys**: the southwestern portion of the Valley, south of the Rio Grande and north and west of the San Luis Hills.
>
> **San Luis Hills**: a prominent series of mesas and eroded hills in the southern Valley. The Rio San Antonio and Conejos flow along the western and northern side of the San Luis Hills. The Rio Grande cuts through the San Luis Hills downstream of its confluence with the Conejos River. The San Luis Hills can be clearly seen on Figure 8 of State's Exhibit No. 6.
>
> **Costilla County**: the Trinchera Creek valley, the Costilla Plain, the foothills of the Culebra Range, and San Pedro Mesa. San Pedro Mesa is the large mesa south of the town of San Luis lying between the Costilla Plain on the west and the Culebra Range on the east.

170. The regions are described in even more detail in State Exhibit 12, Table 20 at pages 74-75 and in the matching diagram of the similar or like hydrological characteristics of particular areas or "parameter zones" for the conceptual model which is found in Figure 15 at p. 76 of State Exhibit 12 and reproduced below. *Transcript (Harmon) Vol. III* at p. 491-97. Eric Harmon

pointed out that while the conceptual model is a vast step forward from the prior knowledge of the Valley, there are many areas in the Valley where the geology and hydrogeology are still poorly understood and that this will affect the groundwater model. In particular, he described the need for further study the areas of Conejos County that are highly complex due to faulting, fracturing, and interbedding with volcanics. In Costilla County there is much to learn about the subsurface volcanic layers and the rift-related faulting with upthrown and downthrown blocks that cause perched water in some blocks. Adding to the complexity is the La Sauses Fault along the Rio Grande. *Transcript (Harmon) Vol. II* at p. 523-27.

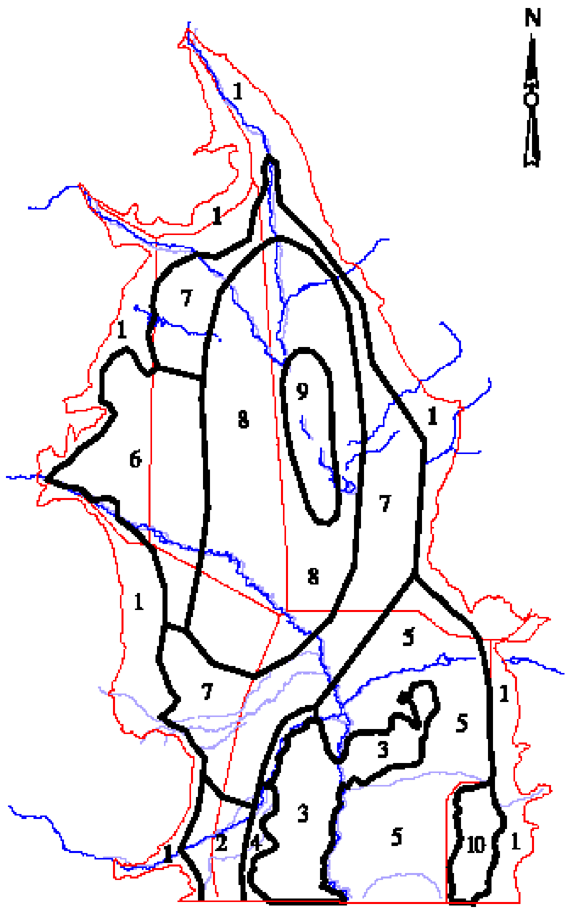


Figure 15: Parameter zones developed for areas of similar hydrogeologic characteristics in the SLV.

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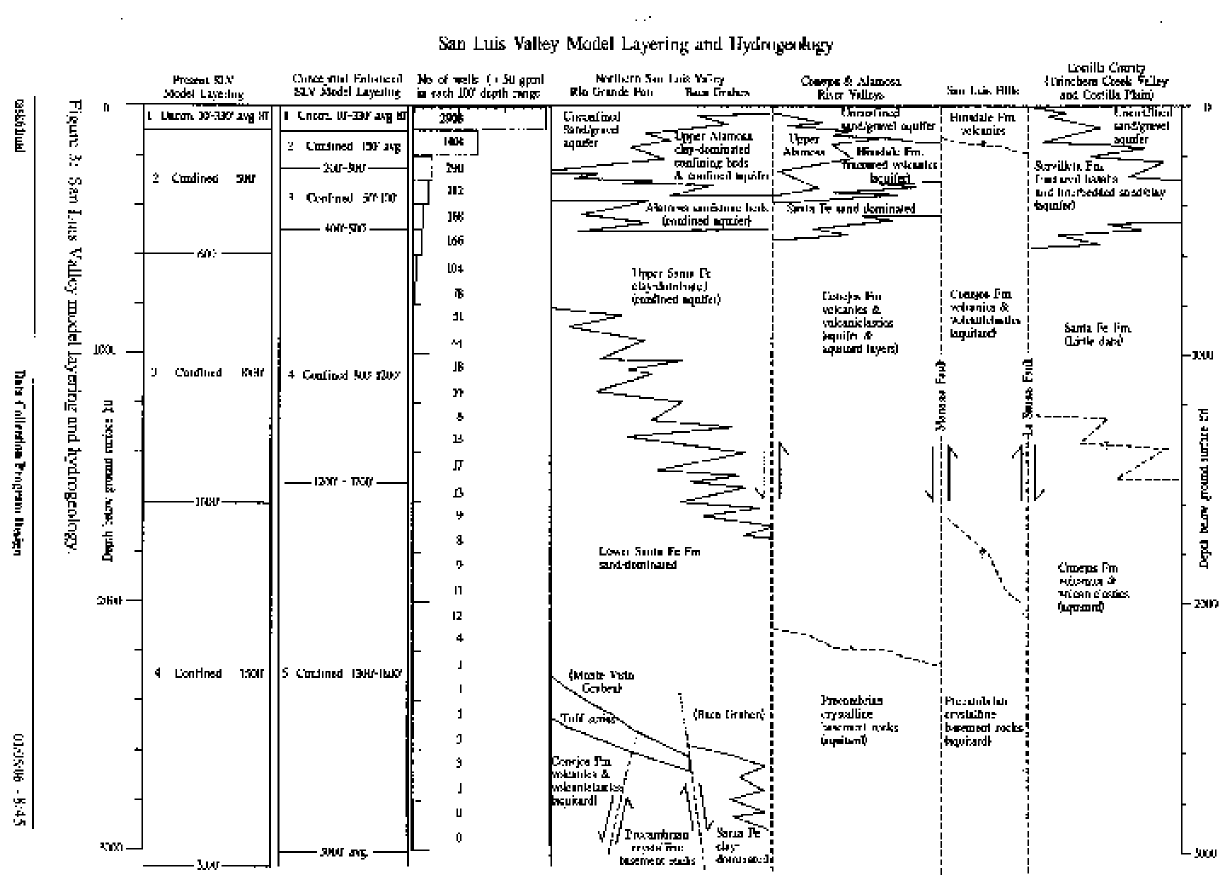
171. The stratigraphy (layering) in each of these regions is important to groundwater occurrence and movement. A generalized schematic view of the stratigraphic relationships between layers in each of these distinct geologic regions of the Valley is contained in State's Exhibit No. 12, Figure 1, "San Luis Valley Model Layering and Generalized Hydrogeology." HRS presented a data collection task report, State Exhibit 72, which included the following schematic of the hydrogeology by the distinct regions in the Valley outlined above and as displayed below with color in Exhibit 12, Figure 1, page 7. The copy from Exhibit 72 is reproduced here as the text reproduced more clearly.



172. Within the San Luis Valley there are geologic structures that form hydrologically important boundaries. One example is the San Luis Hills, which have been uplifted due to faulting relative to the sediments on the east and west sides and which are bounded by faults on all sides. There are subsurface structures in the Closed Basin that control the thickness and extent of some of the aquifer layers. An example of this is the structural trough previously described as the Baca Graben located in the east-central area of the Closed Basin. The Baca Graben is lower than the adjacent Alamosa Horst and, therefore, allowed much thicker accumulations of sediments to form in that area as compared to the central and western portions of the Closed Basin.

173. The following is a description of each of the distinct geologic layers by geographic region, which corresponds to the layers as contained in the conceptual model from which the RGDSS groundwater model derives its parameters. One of the limitations of the MODFLOW computer modeling program is that it requires continuity of layers. Eric Harmon and HRS sought to define a conceptual framework for the groundwater model that would be as accurate as possible given the great variations in the San Luis Valley described above. As shown by the following descriptions, the composition of the layers and therefore their hydrologic characteristics vary from region to region in the Valley. These differences in the hydrologic characteristics in different parts of individual layers, for groundwater modeling purpose, are reflected by different hydraulic parameters contained in the RGDSS groundwater model.

174. Layer 1 is the unconfined alluvial or surficial aquifer, referred to as the unconfined aquifer. It is generally composed of Quaternary Age (less than 2 million years ago) sediments consisting primarily of unconsolidated sand and gravel. In these recent stream alluviums, such as the floodplains of the Rio Grande and Conejos River, the saturated alluvium is continuous and in hydraulic connection with the broader unconfined aquifer that exists outside the river flood plains. See State Exhibit 73, Map 25. *Transcript (Harmon) Vol. III* at p. 469-71.

175. The unconfined alluvial aquifer varies in thickness from less than 50 feet to over 500 feet, and is present across the majority of the San Luis Valley, except in the San Luis Hills. It is generally thinner than in the Closed Basin. It is thickest along the mountain fronts, where the alluvial fans may locally be more than 500 feet thick. In Costilla County, the unconfined alluvial aquifer varies from less than 10 feet to over 200 feet thick, and it is present in most of the Trinchera Creek valley and the Costilla Plain. Valley-wide, unconfined aquifer well yields generally range from 50 to over 1,000 gpm.

176. Layer 2 over the majority of the San Luis Valley represents the upper Alamosa Formation. This is composed primarily of lacustrine (lakebed or marsh environment) sediments consisting primarily of blue-green clay layers that are relatively discontinuous, being separated by thin sand, gravel, or sandstone layers. Considered as a whole, this layer acts as an aquitard, serving to confine the underlying deeper aquifer layers. A large number of small capacity wells are completed in the portions of the upper Alamosa Formation where the interbedded sand or sandstone has sufficient thickness and permeability to support well pumping. See State Exhibit 73, Map 31 and Map 26. *Transcript (Harmon) Vol. III* at p. 470-72

177. In the Closed Basin, the upper Alamosa Formation's thickness varies from very thin near the edges of the San Luis Valley, to over 800 feet thick in the Mosca–Hooper area. In the Conejos and Alamosa River valleys, this formation becomes progressively thinner to the south, with the clays disappearing almost entirely between La Jara and Antonito. This formation is not present in the San Luis Hills.

178. The thick blue-gray lacustrine clay layers of the Upper Alamosa Formation present in the Closed Basin are not present in Costilla County except in isolated places. In this area there does exist, however, a series of discontinuous clay and sand layers that act primarily as an aquitard in most areas of the county. This layer ranges from less than 20 feet to over 100 feet thick; and in some localized areas, it has a sufficiently high percentage of sand to constitute an aquifer capable

of supporting well production in the range of 50 to 500 gpm. *Transcript (Harmon) Vol. III* at p. 472

179. Layer 3 is the sandstone-dominated portion of the Alamosa Formation. This layer represents part of the Alamosa Formation in the majority of the Valley and is composed generally of at least 50% sand or sandstone layers. This formation also constitutes the top relatively continuous confined aquifer below the overlying clay series and is capable of providing high yields to wells, in the range of 100 gpm to over 2,500 gpm. See State Exhibit 73, Map 32 and Map 27. *Transcript (Harmon) Vol. III* at p. 472-74

180. Evidence from drilling logs, geophysical logs, and water level measurements show that this layer is in continuous hydraulic connection with the underlying, deeper confined aquifer layers. While the layers in the confined aquifer are distinct and can be separately identified by their lithology and aquifer characteristics, in most areas of the San Luis Valley these layers form a continuous, interconnected Confined Aquifer System.

181 In the Conejos and Alamosa River valleys, Layer 3 is the Alamosa Formation sandstones and the underlying Santa Fe Formation sands and sandstone layers, which are interbedded with the Hinsdale Formation basalt lava flows. These lava-flow layers vary from thin and highly fractured to very thick and unfractured. Together the fractured lava flows and the interbedded sandstone layers form a productive confined aquifer in this region. In these areas the aquifer permeabilities are generally high and well yields can exceed 3,000 gpm. The total thickness of the interbedded sediments and volcanic rocks varies from less than 200 feet on the western edge of the San Luis Valley to over 800 feet in the Conejos and Alamosa River valleys. The thick and unfractured lava flows form a confining layer or aquitard.

182. With the exceptions of a thin and unsaturated Hinsdale basalt caprock and small, isolated erosional remnants, the Hinsdale, Alamosa, and Santa Fe Formations are not present in the San Luis Hills.

183. In Costilla County, Layer 3 is the Servilleta Formation, consisting primarily of basalt lava flows. This formation is composed of layers of fractured lava flows interbedded with sand and clay. The Servilleta Formation has high permeability due to fracturing, and well yields from this aquifer range from 500 to over 2,500 gpm. The Servilleta Formation varies in thickness from less than 50 feet to approximately 350 feet. It is located primarily south of the San Luis Hills and is not present in the Closed Basin or, to any significant degree, in the Conejos or Alamosa River valleys. *Transcript (Harmon) Vol. III* at p. 474

184. Layer 4 is a confined aquifer layer that, over the majority of the San Luis Valley, is composed of Santa Fe Formation sediments. This layer generally is composed of 30% to 60% sandstone and conglomerates. It provides relatively high well yields (generally 100 to 1,500 gpm), although the available data indicates that it has a generally lower permeability than the overlying Alamosa Formation sandstone. This confined aquifer layer, although tapped by some wells, has fewer wells than the Alamosa Formation due to its greater depth. This layer is in continuous hydraulic connection with the overlying Alamosa sandstone and deeper, underlying confined aquifer layers. See State Exhibit 73, Map 33 and Map 28. *Transcript (Harmon) Vol. III* at p. 474-76

185. Layer 4 in the Conejos and Alamosa River valleys is represented by the Oligocene Age (35 to 25 million years ago) Conejos Formation volcanic and volcaniclastic rocks. The composition of these deposits vary greatly, but in general they act as a relatively low permeability layer due to the high degree of compaction, cementation, and the presence of clay-rich minerals caused by the chemical weathering of the volcanic source rocks. This layer has not been completely penetrated by wells in this area, however, based on regional geophysical surveys and comparison with the Conejos Formation in the nearby San Juan Mountains, it is estimated to be up to 2,000 feet thick. This formation is not considered an aquifer in this region due to its overall relatively low permeability, although there are areas of higher permeability.

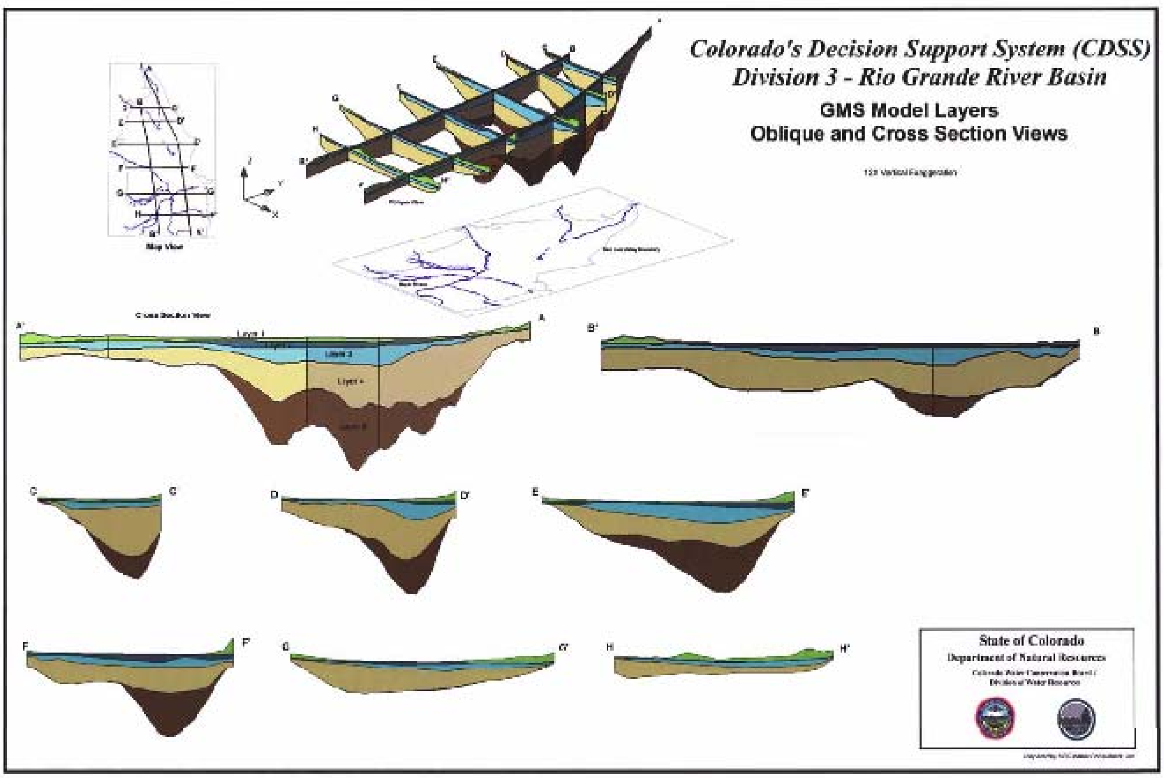
186. The San Luis Hills form a topographic barrier between the Conejos River and the lower Rio Grande in Colorado. The hills are a relatively low permeability aquitard. The water-saturated zone in the hills is composed almost entirely of Conejos Formation rocks of relatively low permeability. In the RGDSS groundwater model Layers 1 through 4 in the San Luis Hills are represented by this material. And, for the reasons discussed below, RGDSS groundwater model Layer 5 is not present in the San Luis Hills.

187. In Costilla County, RGDSS groundwater model Layer 4 represents Santa Fe Formation, the Conejos Formation, and volcanic and volcaniclastic rocks. Relatively little is known about these formations in this area, because few wells penetrate them. The available evidence indicates that the Santa Fe Formation consists of poorly cemented sandstone and conglomerate interbedded with up to 50% clay layers. Based upon regional geophysical data, the Santa Fe Formation is estimated to be up to 1,000 feet thick in this region. And based upon regional geologic mapping, the Conejos Formation in Costilla County is believed to underlie the Santa Fe Formation. No wells are known to penetrate this formation in the Costilla County region. The Conejos Formation is estimated to be of relatively low permeability based on its characteristics in adjacent regions, such as the San Luis Hills, and its thickness is estimated at up to 2,000 feet based on regional geophysical data and from the thickness of the formation in other areas. *Transcript (Harmon) Vol. III* at p. 476-77

188. Layer 5 is the deepest layer of hydrologic significance, consisting of a series of relatively well-cemented conglomerate and sandstone beds of the Santa Fe Formation, generally with greater than 60% clay. It is present only in the north-central Closed Basin area, where these sediments reach their greatest depth in the San Luis Valley. This layer varies from an estimated 1,000 feet to over 4,000 feet thick, but its top is generally deeper than 2,000 feet below ground in the Closed Basin. Below the Santa Fe Formation there are relatively well-cemented sedimentary rocks and volcanic tuffs, some of which predate the rifting that created the Valley. Though data on this layer is relatively sparse, the existing evidence shows that these sediments are of relatively low permeability. This layer is not generally used as a source of groundwater due to its great depth, low permeability, and indications of relatively poor water quality. Layer 5 is not present in the other geographic areas of the Valley, because the available evidence indicates that the rocks at those depths have low permeability, poor water quality, and are therefore not considered to be aquifers. See State Exhibit 73, Map 29 and Map 34.

189. As is evident from the foregoing descriptions, the San Luis Valley has a unique, varied and complex hydrogeologic structure, portions of which are not yet well understood. As illustrated by Figure 4 and Table 6 of State's Exhibit No. 10, there is not a uniform distribution

of well construction data, either by depth or location in the Valley. Generally speaking, less data is available the deeper one goes into the Valley's aquifer systems, and the data is most sparse in the deeper layers for the east and southeast portions of the Valley. This lack of data makes it more difficult to draw accurate conclusions about the effects of well pumping in these areas and at these depths. The complexities described above were visually depicted by Eric Harmon and his colleagues at HRS in Exhibit 73, Task 32, Figures 1-35. Below is Figure 35 illustrating oblique and cross section views of the Valley which assist in understanding the different layering described above.



Map 35

3. Formation of Confined and Unconfined Aquifers

190. The available geologic evidence establishes that approximately 5 million years ago lava flows from the San Juan volcano field created a dam across the lower end of the San Luis Valley, the remnants of which are the San Luis Hills. As noted above, during that time the water that flowed into the Valley was trapped behind that dam and could not flow out. During this same time period the rifting of the Valley was continuing and the sediments that washed in from the

San Juan and Sangre de Cristo Mountains filled the subsiding portion of the Basin. The dam created a lake in the Valley in which were deposited the blue-green lacustrine clays, the blue clay series known locally as the "Blue Clay." The sources of this clay were weathered volcanic rocks in the San Juan Mountains and sediments from the Sangre de Cristo Mountains. The unique environment in which the clays were deposited was characterized by slow-moving streams and marshes, an environment in which the clays were nearly continually water saturated as they were slowly buried in the subsiding basin. This lake environment with its slow moving streams resulted in the extensive interbedding of sands and clays that characterize much of the confined aquifer north of the San Luis Hills. The blue clay series is sometimes referred to as the "Alamosa Formation," *Transcript (Harmon) Vol. II* page 340. The blue color of the clay indicates that it has been submerged its entire geologic life, as once exposed to air, the clay turns rust or brown in color. *Transcript (Harmon) Vol. II* page 341.

191. The real extent of this lake environment is generally marked by the extent of the so-called "blue clay" separating the confined and unconfined aquifers. State's Exhibit No. 77, previously reproduced on page 11 of this opinion, is a map showing the general boundaries of the blue clay series and hence the area beneath which the confined aquifer in the San Luis Valley is located. The extent of the blue clay series is also shown on State's Exhibit No. 113 (attached as Appendix B). It generally exists from the San Luis Hills on the south to near Villa Grove on the north, and extends east and west to within several miles of the mountain fronts. The area between the edge of the blue clay series and the mountain fronts is referred to as the "recharge zone" or "transition zone." It represents an area where the confining clay series is not present and groundwater recharge in that area can go into either the confined aquifer or the unconfined aquifer, depending upon local groundwater flow gradients. The blue clay series abuts the San Luis Hills on the west and north. This is an area that has historically been characterized more by discharge from the confined aquifer than by recharge to the confined aquifer. *Transcript (Harmon) Vol. II* pages 272-73.

192. The blue clay series, while extensive, is not a single clay layer. Rather, it consists of many discontinuous clay layers that collectively create the areally extensive aquitard that defines the confined aquifer and restricts the upward movement of water from the confined aquifer to the unconfined aquifer. Since the clay layers are not co-extensive or of equal thickness, it is possible for water to "leak" from the confined aquifer into the unconfined aquifer. On a regional basis this upward leakage constitutes a large volume of water but is comparatively small on a unit basis. This comparatively small rate of upward leakage is demonstrated by the leakance tests performed by Mr. Harmon and by the fact that it was not until the construction of large canals that brought large quantities of water from the Rio Grande into the Closed Basin that the unconfined aquifer in the Closed Basin began to fill. Had there been large quantities of upward leakage from the confined aquifer into the unconfined aquifer in the Closed Basin, the depths to water in the unconfined aquifer would not have been the 40 to100 feet prior to diversion of canal into the Closed Basin. See generally, State Exhibit 39, *Joint Investigation* at p. 67. Likewise, if there were large quantities of upward leakage, one would not expect to see the large water level declines experienced in the unconfined aquifer of the Closed Basin in recent years. See generally, *Transcript (Harmon) Vol. II & III.*

193. There are two means of outflow from the confined aquifer in addition to upward leakage. The first is by direct discharge, principally in the form of springs. The second is by groundwater

withdrawals through flowing or pumped wells. See generally *Joint Investigation* at p. 57-58. Examples of springs that discharge directly from the confined aquifer are Diamond Springs, Russell Springs, and McIntyre Springs.[22] The locations of these springs are shown in Figure 3 of State's Exhibit No. 10. See generally, *Powell* at pp. 36-39. Since the 1890's the Valley has had a large number of small-diameter confined aquifer flowing wells used principally for irrigation, stock watering and domestic use. See generally State Exhibit 38.01 *Siebenthal*, pages 57-92. There are no records for many of these wells, but during the RGDSS Study, a significant effort was made to develop estimates of the locations and flow of these wells. In addition to these small capacity wells, large capacity wells are used for irrigation and municipal purposes in the Valley pursuant to their adjudicated decrees.

194. Prior to the litigation brought in 1966 by Texas and New Mexico against Colorado for violation of the Rio Grande Compact, water users in the San Luis Valley allowed artesian wells to flow year round. As a consequence of this litigation, the Rio Grande Water Conservation District undertook an extensive program of capping and valving the confined aquifer wells in the Valley. *Transcript (Vandiver) Vol. I* page 111, 140. Its purpose was to reduce the amount of water flowing out of the confined aquifer, to help restore artesian pressure, and to reduce stream depletions caused by declines in artesian pressure.

195. The artesian pressure in the confined aquifer reflects the combined effect of all inflows to and outflows from the confined aquifer. When inflows exceed outflows, the artesian pressure will increase; and when outflows exceed inflows, the artesian pressure will decline. These changes in artesian pressure are the result of natural process such as periods of increased and decreased precipitation and the stresses of use by man, which tend to work in parallel with the forces of nature. When precipitation is more abundant, water users withdraw less water from the confined aquifer. In times of drought or low precipitation, man makes greater use of the confined aquifer. The combined effects of these forces on artesian pressure levels in the confined aquifer can be seen in the confined aquifer wells with long-term records of water levels or pressures. See e.g. State's Exhibits No. 80.02, 80.03, 80.16, 80.18, 80.22, and 80.24.[23]

196. Prior to 1960 there was no long-term monitoring of water levels or artesian pressure levels in the confined aquifer. See State's Exhibit No. 12, Tables 10 and 11 and Figure 11. Beginning in 1960 and continuing to the present, the number of long-term monitoring wells in the confined aquifer has grown substantially. *Id.* As illustrated by the hydrographs for the artesian wells shown in State's Exhibits No. 81.01- 81.04,[24] the artesian pressure has varied depending upon the climatic conditions in the Valley. From 1978 to 1979, following the drought in 1977, the artesian pressure in many areas of the Valley was at one of its lower points of record. Following the wet period of the mid-1980's the artesian pressure recovered substantially and, with some exceptions, fluctuated within this range at least through 2000. The drought that began in the San Luis Valley by 2000 and which appears to be continuing to the present, caused artesian pressures to decline in some areas of the Valley to levels at or below any previously recorded. The year 2002 combined record lows in snowpack and unprecedented pumping with the predictable result of dramatic decline in artesian pressure across the entire San Luis Valley.

[22] The hydrograph of discharge from McIntyre Springs is reproduced on page 18.
[23] 80.24 is reproduced on page 17.
[24] 81.01 is reproduced on page 17.

197. The confined aquifer has been the source of a good deal of speculative interest in the water development community. See e.g. *Application of American Water Development, Inc.*, Case No. 1986 CW 46, District Court, Water Division No. 3; *Am. Water Dev., Inc. v. City of Alamosa*, 874 P.2d 352, 384 (Colo. 1994). This has been driven, in part, by the suggestion that there is 2 billion acre-feet of water in storage in the confined aquifer. This suggestion was first made by Mr. Philip Emery, an investigator for the USGS responsible for many of the pioneering studies of the hydrology of the Valley that the USGS carried out in the late 1960's and early 1970's. As explained by Mr. Harmon, this "back of the envelope" calculation by Mr. Emery was just that, and it does not represent at all what is currently known about the hydrogeology of the Valley. Mr. Harmon further explained that although there is a large volume of water in the confined aquifer, at depths greater than 3,000 feet below ground, the water quality degrades very rapidly, and even if economically recoverable, that water would not be practical for any known use. In addition, there are substantial practical hurdles to producing this water. In Mr. Harmon's opinion the production of large quantities of water from the confined aquifer would require removal of the artesian pressure from the entire aquifer, top to bottom, which would be physically difficult to accomplish, even with a large capacity well on every section corner in the Valley. The San Luis Valley as a whole contains less than half the quantity of groundwater estimated by Mr. Emery, a part of which is of unusable quality and a part of which is not economically recoverable. *Transcript (Harmon) Vol. III* at pages 527- 531 and pages 546-47. Thus, the Court concludes that the claims about the large quantities of water available for withdrawal in the confined aquifer in the Valley have been substantially over-stated and simply serve to obscure rather than advance any thoughtful analysis of the confined aquifer and the consequences of new withdrawals from that aquifer. The fact that the best estimate today is that there is less than one half of the water in storage than what we believed only thirty years ago is also a strong indicator that this Court should be cautious in committing to irreversible actions based on past or current hypotheses which may or may not prove accurate.

4. Groundwater Flow and Stream-Aquifer Interaction

198. Figures 6 and 7 of State's Exhibit 12 are schematic diagrams that illustrate the groundwater flow regime in the Valley. Figure 6 shows that the general pattern of groundwater movement in the Valley is radial, it moves inward from the Valley's edges toward the center. Groundwater moves from the recharge areas, which primarily are the higher topographic areas on the periphery of the Valley, into the center of the Valley. In the Closed Basin, groundwater then tends to discharge and collect in the sump area, which has no natural surface outlet to the Rio Grande.

199. Figure 7 shows in cross section that water recharged along the Valley edges moves downward and also toward the center of the Valley. *Transcript (Harmon) Vol. II* pages 364. Part of the recharged water moves into the confined aquifer, and part of it moves into the unconfined. Toward the center of the Valley, groundwater from deeper layers moves upward through clay beds because the artesian pressure in the confined aquifer is higher than the water table in the unconfined aquifer. This upward-moving groundwater eventually reaches the unconfined aquifer. Discharge from the unconfined aquifer in the Closed Basin occurs through well pumping, through evapotranspiration by phreatophytes and subirrigated meadows and alfalfa, and by evaporation when the water table is at or near the ground surface.

200. There is significant interaction between the aquifers and streams in the Valley. Generally speaking, the streams lose water to the aquifers in their upper reaches, providing groundwater recharge. A prime example of this is the small rim-inflow streams discussed below. Other examples are the Rio Grande, which is often a "losing" stream from where it enters the Valley near Del Norte, downstream to Seven Mile Plaza, and the Conejos River above Antonito, where it is also a losing stream. On the lower end of the stream systems the general pattern is reversed, the streams tend to gain water from groundwater discharge. Again examples of this include the Rio Grande downstream of the Rio Grande County and Alamosa County lines, and the Conejos River and the Rio San Antonio downstream of Manassa. See generally *Powell* at p. 32; *Joint Investigation* at p. 57; *Siebenthal* at pp. 55-56.

201. Many of the smaller streams that enter the Valley from the San Juan Mountains to the west and the Sangre de Cristo Mountains to the east often have live flow when entering the Valley immediately downstream of the mountain front. Typically, where these streams enter the Valley the undiverted streamflow leaks downward and recharges the aquifer system due to the relatively high permeability of the alluvial fan materials and the fact that the streams are typically not in connection with the regional groundwater table in their upper reaches. *Id. Transcript (Harmon) Vol. III* at p. 496. Accordingly, except for years of high snowpack or during other large precipitation events, these streams are intermittent or ephemeral in their lower reaches. These rim-inflow streams are important sources of water to the aquifer system of the Valley, but only infrequently contribute surface flow to perennial surface streams.

202. Despite the lack of connection of these streams to the regional groundwater table, the regional groundwater level does play an important role in which aquifers are recharged by this rim-inflow. When the artesian pressure in the confined aquifer is higher, a greater portion of this water will recharge the unconfined aquifer; and when artesian pressures are lower, a greater percentage of this water will recharge the confined aquifer and less will be available to flow into the unconfined aquifer and recharge the same.

203. Likewise, the relative level of artesian pressure in the confined aquifer affects the flow of streams as they cross the recharge zone. Perennial streams such as Saguache Creek, San Luis Creek, the Rio Grande, the Conejos River, the Alamosa River, La Jara Creek, and Médano Creek all flow across the recharge zone before reaching the edge of the blue clay series. If the artesian pressure in the confined aquifer is reduced, the groundwater level in the recharge zone will likewise decline. This decline in groundwater levels below the streams and creeks will cause either a decrease in stream gains from the lowered water table or an increase in losses from the surface flow into the aquifer system. The effect of either is to reduce stream flows. See generally *Transcript (Harmon) Vol. XXV* at p. 4819-21.

204. The confined aquifer and its artesian pressure regime are therefore of special significance to the stream systems in the Valley. In effect, the confined aquifer and its artesian pressure are the foundation upon which the surface streams and unconfined aquifer rest. *Transcript (Davey) Vol. IV* at p. 772. The Protestors' experts did not dispute that withdrawals from the confined aquifer will impact stream flows and the unconfined aquifer or that the confined aquifer provides hydraulic support for the streams. See *Transcript (Lytle) Vol. XXIII* at p. 4230. If the water level in the confined aquifer is allowed to decline appreciably or if the historical regime is fundamentally altered so that the water levels and artesian pressure are permanently lower, then

the surface streams in the Valley will suffer increased losses, water levels in the unconfined aquifer will decline, and wetland areas created by the shallow unconfined aquifer will dry up. If sufficient lowering occurs in the confined aquifer, many areas of the unconfined aquifer will effectively drain into the confined aquifer. Any reduction in flow to the Conejos River, the Rio Grande, and their tributaries, from such a lowering of artesian pressure will mean that a greater percentage of the flow of those streams must be used to satisfy Colorado's delivery obligations under the Compact, thereby reducing the amount of surface water available for diversion by surface water rights, including particularly those that pre-date the Compact. Thus, the Rules properly require a judicially approved plan for augmentation for any new or increased withdrawal of groundwater from the Confined Aquifer System, including mitigation of changes in artesian pressure and replacement of depletions to surface streams in order to prevent injury to water rights and to prevent interference with Colorado's ability to comply with its Compact obligations.

5. Piezometer Construction and Test Pumping

205. High quality pumping tests allow analysis of transmissivity and storativity and, depending upon the aquifer and well conditions, analysis of leakance. Good quality data for these parameters are needed in order to build an accurate conceptual model of the hydrogeology of the San Luis Valley and to translate that conceptual model into a reliable numerical groundwater model. In 1999, HRS made specific recommendations for the gathering of new high quality well testing in its Data Collection Report Final Design-Task 6, admitted as State Exhibit 72. The RGDSS Study gathered all known data about the aquifers and well testing but recognized this data was too limited to form a sound database for any groundwater model. New test wells were proposed, built and monitored in key locations throughout the Valley to gather necessary information. Of course, there were time and financial limits to this project. See generally *Transcript (Harmon) Vol. II* at p. 366-403.

206. Since high quality pumping tests were sparse in the San Luis Valley, particularly in the confined aquifer, during Phases 1 and 2 of RGDSS, 15 confined aquifer piezometers (monitoring wells) were drilled and completed at the locations shown on Figure 13 of State's Exhibit No. 12. An aquifer test was conducted at each location using an existing well as the pumping well and using each piezometer as one of several monitoring points for each test. The cost of groundwater data acquisition is high, and the State spent approximately $1.3 million on the piezometer drilling and aquifer testing program. See State's Exhibit No. 12, Table 13. Even though the cost was high, the expenditure was considered necessary to satisfy the need for aquifer parameter values in the confined aquifer that could be used to better understand the aquifer system and to aid in developing a more reliable groundwater model. The data on aquifer characteristics obtained from these pumping tests is summarized in Table 15 of State's Exhibit No. 12.

207. A second purpose of the aquifer test was to obtain data on aquifer compaction. The State was concerned that the nature of the clays in the confined aquifer made them susceptible to compaction, with resulting land subsidence, if artesian pressures were lowered to too great an extent or for too long a time. To this end, 14 of the 15 RGDSS piezometers were equipped with extensometers. An extensometer is a devise that allows the measurement of aquifer compaction during the test pumping of a well. A schematic diagram of a RGDSS piezometer with an extensometer is shown in Figure 14 of State's Exhibit No. 12, and the results of each aquifer test

monitored by an RGDSS piezometer are contained in State's Exhibits No. 42 through 71. The use of an extensometer for purpose of measuring aquifer compaction is also discussed in State's Exhibit No. 41, *Land Subsidence in the United States*, U.S.G.S. Circular 1182 at pp. 146 - 148.

208. The aquifer testing program utilized an existing well as the pumped well, and utilized the RGDSS piezometer and other adjacent wells as monitoring wells to monitor the effects on the aquifer of pumping the well. The observation wells and piezometer were completed (perforated) in the same aquifer intervals as the pumped well. The test pumping generally lasted 72 hours, during which time the piezometer and other observation wells were monitored for water level drawdown caused by the pumped well. This information was then analyzed to obtain the values for aquifer transmissivity, storativity, and leakance.

209. All RGDSS pumping tests, with the exception of P4, were of sufficiently long duration and yielded quality data from which reliable estimates of transmissivity, storativity, and composite leakance could be made. This information was a significant improvement in the database of hydrogeologic information in the San Luis Valley, particularly with respect to leakance. During and after these pumping tests, the extensometers were also measured to determine the amount of elastic aquifer compaction that occurred during the pumping test and the rate of recovery after the conclusion of the pumping test. The results of the extensometer readings and the amount of elastic aquifer compaction that occurred during the test are summarized in Table 22 of State's Exhibit No. 12. One purpose of the requirements of Rule 6 is to prevent land subsidence. Because the Protestors challenged the potential for land subsidence from new withdrawals, the Court will address the evidence on the potential for land subsidence.

6. Potential for Land Subsidence

210. As discussed previously, much of the confined aquifer is composed of interbedded sands and blue-green lacustrine clays. In many areas of the confined aquifer, the lacustrine clays predominate. And, as discussed above, these clays have as their source weathered volcanic rock. The volcanic rocks of the San Juan Mountains are rich in feldspar, which, through erosion and chemical weathering, creates clay particles in the montmorillonite mineral family, the most compressible of clay minerals when deposited in aquitards. State's Exhibit No. 74, Francis S. Riley, *Assessing the Potential for Land Subsidence in the San Luis Valley, Colorado; A Preliminary Exploration*.

211. The mechanics of aquitard compaction are explained in State's Exhibits No. 41 and 74 and were set out in the testimony of Eric Harmon. *Transcript (Harmon) Vol. II* at p. 408-438, *Transcript (Harmon) Vol. III* at p. 443-450. As explained in greater detail in those exhibits and the testimony of Eric Harmon, there are two general types of aquitard compaction – elastic (recoverable) and inelastic (non-recoverable) compaction. Elastic compaction, also called reversible deformation, occurs when the pore-fluid pressure in the aquitard is reduced transferring to the "aquifer skeleton" the load previously supported by the fluid pressure. When the pore-fluid pressure in the aquifer is restored, the aquifer skeleton expands. This is the type of recoverable aquifer compaction measured by the extensometer in the RGDSS piezometers. State's Exhibit 12, pp. 82-84, Table 22.

212. Inelastic or non-recoverable compaction, on the other hand, irreversibly alters the aquifer skeleton. In this circumstance the maximum load (pressure) on the aquifer skeleton exceeds the previous maximum "preconsolidation stress." When this occurs the clay particles that comprise the aquifer skeleton may undergo significant and permanent rearrangement, resulting in irreversible compaction. In effect the water is squeezed out of the pore spaces in the aquitard, and the remaining pore space is reduced by the rearrangement of the clay particles. This process results in the permanent loss of aquifer storage capacity and is illustrated on pages 8 and 9 of State's Exhibit No. 41. The aquitards, that is, the clays in the confined aquifer and the clays separating the confined aquifers from the unconfined aquifer are the types of clay that are subject to irreversible compaction and, if that occurs, land subsidence will likewise occur. The role of aquitards in compaction and the resulting land subsidence is also illustrated and explained on pages 10-11 of State's Exhibit No. 41 The extent of the land subsidence will be a function of the extent to which the artesian pressure in the confined aquifer is reduced and the duration of that reduction. The available evidence indicates that there is potential for significant land subsidence in the Valley from new or increased groundwater withdrawals from the confined aquifer. See State's Exhibit No. 12, at pp. 83-87; State's Exhibit No. 74.

213. The Protestors disputed the potential for land subsidence. They asserted that the State has performed no specific study to evaluate the potential for land subsidence due to aquitard compaction, that the sediments in the Valley are subject to "over-consolidation," and therefore are not subject to compaction, and that temperature variations, not compaction, better explain the variations in the RGDSS extensometer measurements.

214. The Court finds that the results of the extensometer measurements combined with Mr. Harmon's personal experience with well construction in the San Luis Valley and his physical examination of the clays of the confined aquifer, are both a specific study and credible scientific evidence of the unconsolidated nature of the clays and the potential for aquifer compaction and land subsidence in the San Luis Valley. Mr. Harmon's analysis of geophysical data from deep oil and gas wells drilled in the Valley, State's Exhibit No. 105, demonstrated that at great depth in the Valley the clays have been compressed or consolidated, but at depths shallower than about 3,000 feet the clays have significant porosity and therefore have not been "over-consolidated." Mr. Harmon looked at known data concerning land subsidence related to withdrawal of groundwater from the San Joaquin Valley in California and similar data from Texas and Arizona. *Transcript (Harmon) Vol. III* at p. 444-46. See also State's Exhibit No. 12, at pp. 83-87; State's Exhibit No. 74. Mr. Harmon's conclusion is in agreement with that of Dr. Riley; State Exhibit 74, Francis S. Riley, *Assessing the Potential for Land Subsidence in the San Luis Valley*, page 32, that "There is nothing in the available data that contradicts the conclusion of Riley and Harmon that the sequence of unconsolidated terrestrial deposits underlying the central San Luis Valley is at least as vulnerable to irreversible compaction as the similar sediments involved in the subsidence in the San Joaquin Valley, California." Phillip Emery expressed precisely the same concerns in 1973 when he observed the decline in artesian pressure in parts of the San Luis Valley.[25] Emery observed, at page 22:

[25] Phillip A. Emery, Robert J. Snipes, John M. Dumeyer, and John M. Klein, *Water in the San Luis Valley, South-Central Colorado in 1973,* USGS , Colorado Water Resources Circular 18, State Exhibit 86

> A potential water-management problem that should be considered is land subsidence. De-watering, or lowering the head appreciably, in the confined aquifer could result in irreversible compaction of the aquifer and cause land subsidence. No land subsidence has been detected in the San Luis Valley, but the potential exists. Land subsidence due to excessive ground-water withdrawal has occurred and is well documented, in similar alluvial basins.

215. There is no credible evidence to suggest that temperature variations were the cause of the recoverable compaction measured by the extensometers used in the testing program. As explained by Mr. Harmon, the extensometers were left in-situ for a week or more before the pumping tests were conducted and therefore had reached thermal equilibrium with the surrounding groundwater before any measurements were taken. The flow through the piezometers induced by pumping a separate well located hundreds and, in most cases, more than 1,000 feet from the piezometer, was simply too small to change this fact, even if the test pumping had caused a change in the temperature of the water in the piezometer. *Transcript (Harmon) Vol. XXV* at p. 4828, ln. 10 – p. 4835, ln. 5

216. Once compaction occurs it is irreversible. There is a significant potential for aquitard compaction of the clays in the confined aquifer if confined aquifer artesian pressure levels are drawn-down below the previous lows. The aquitard compaction is slow but irreversible and results in a corresponding irreversible subsidence of the overlying land. State's Exhibits No. 12, 41, 74, and 127. Aquitard compaction would reduce the amount of water bearing in the clays and thus would directly affect the yielding capacity of the confined aquifer. In turn, less storage would impact the drawdown and cone of depression for existing or future wells in the confined aquifer. *Transcript (Harmon) Vol. III* at p. 446-47. See also Exhibit 12, App. B pp. 78-84; Exhibit 74, Francis S. Riley, *Assessing the Potential for Land Subsidence in the San Luis Valley.*

217. The conclusions reached by Francis Riley and Eric Harmon were challenged as based on limited evidence. The comparison of 1985 measurements of elevations to 1933 elevations along Highways 285 and 17 from Ojo Caliente, New Mexico to Poncha Springs, Colorado, showed evidence of some subsidence, especially north of Alamosa. This evidence must be viewed with some caution given the limited number of points to compare, the possibility of errors, and the likelihood that some of the changes are due to continued fault activity especially at the north of the San Luis Valley. Exhibit 74, Francis S. Riley, *Assessing the Potential for Land Subsidence in the San Luis Valley,* at pages 22-31.

218. Still, this comparison would make any reasonable person cautious and anxious to pursue additional research. As evidenced above, the specific well studies performed indicated clear risk of compaction in the blue clay layers if they are dried out as a result of a lowered artesian head. The RGDSS will grow in its knowledgebase and accuracy of description and predictive ability over time as data accumulates. The MODFLOW component for subsidence became available during the time the groundwater model was being constructed and has not yet been incorporated into the model. That omission does not undermine the credibility of the testimony or opinion of Eric Harmon. The Court finds that the testimony and evidence support the opinions of Eric Harmon that the vast majority of the clay layers in the confined aquifer are not currently compacted and have never been compacted, but that loss of pressure head in the confined aquifer

is significantly lowered from the historic levels by new or increased withdrawals would cause irreversible compaction.

219. The General Assembly and the State Engineer properly considered the potential for land subsidence due to aquitard compaction. The impact of the compaction on the aquifers and their transmissivity and interconnections is clearly a proper subject for both legislative protection of the aquifers and for rulemaking. To ignore this danger until irreversible compaction has occurred would be irresponsible folly. To the contrary, it is logical and reasonable to act with great caution to ensure the porous water-bearing clays are not dried out and irreversibly compacted.

B. Stream and Rim Inflow

220. As described above, there is a significant interaction between the flow of surface streams and the groundwater system in the San Luis Valley. The inflow to the groundwater system in the Valley is an important part of the groundwater water budget and the RGDSS groundwater model. Rim inflows to the Valley were estimated on two prior occasions. In the early 1970s the U.S.G.S. estimated flows from approximately 24 ungaged drainage areas around the perimeter of the Valley for the period 1924 to 1969 (Colorado Water Resources Circular 18, 1973). See State's Exhibit 1, *RGDSS Ground Water Model Documentation*, App. O. In the early 1990s, the State estimated rim inflows for the period 1970 to 1988 and included a more detailed delineation of contributing drainage basins. *Id.* As part of the RGDSS Study accurate estimates of stream flow and rim inflow for the period 1950-2002 were developed. This process is documented in Appendix O to State's Exhibit No. 1 and in State's Exhibit No. 7.

221. The RGDSS groundwater model explicitly represents twelve relatively major perennial streams in the San Luis Valley: the Rio Grande, the Alamosa River, La Jara Creek, the Conejos River, the Rio San Antonio, Costilla Creek, Culebra Creek, Trinchera Creek, Médano Creek, Sand Creek, San Luis Creek, and Saguache Creek. For most of these streams the existing USGS gaging stations provided the necessary stream flow data, and no adjustments were needed to fill in missing or incomplete records or to adjust for diversions. Some adjustments were required to the available data for Culebra Creek, La Jara Creek, the Rio San Antonio, Médano Creek and San Luis Creek. This data and the adjustments to the data were uncontested.

222. As part of the RGDSS Study eleven new stream gages were installed to provide additional rim inflow data. The new gages were installed on Cherry Creek, Cottonwood Creek, Cotton Creek, Deadman Creek, Garner Creek, Major Creek, Rito Alto Creek, San Isabel Creek, South Crestone Creek, Spanish Creek, and Willow Creek. The gages on Cottonwood Creek and Cotton Creek had some historical data but had been abandoned for a number of years. *Id.* This additional gage data, along with the need for groundwater recharge information through 2002, warranted a re-evaluation of rim-inflows and development of new estimates of groundwater recharge from these sources. *Id.*

223. Once the new estimates of rim-inflows were developed for the gaged streams, that data was used to develop estimates of rim-inflows for other small drainages that did not have gages. Once a comprehensive set of rim-inflow estimates were developed, those estimates were used to estimate recharge to the groundwater system from the rim-inflow streams. The results of this

study identify the drainage areas for each of the rim-inflow streams, either as a single stream or combined with others, estimate the stream flows remaining after diversions, and estimate the recharge to the groundwater system for each drainage basin. *Id.* All of this information was then used to provide input for the RGDSS groundwater model. See also *Transcript (Slattery) Vol. VIII* at p. 1573, ln. 20 – p. 1574, ln. 16; see also State's Exhibit 117-D (below); State's Exhibit 1, *RGDSS Ground Water Model Documentation*, App. G., p. 17. All of this evidence was uncontested.

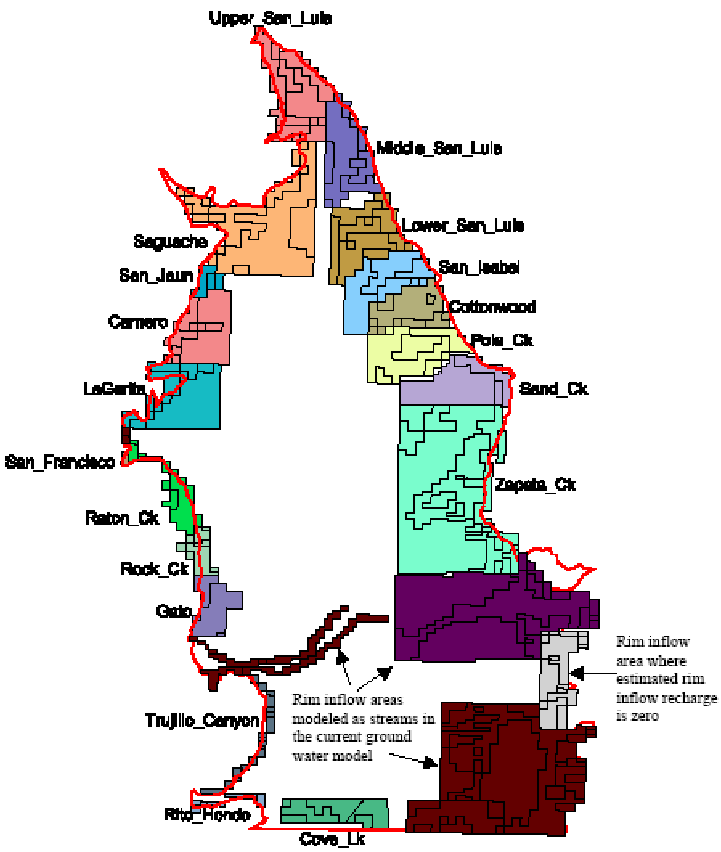


Figure 1. Rim inflow zones included in the current San Luis Valley ground water model. Grey area represents rim inflow zone included in the State's 1991 ground water model, but where estimated recharge from rim inflow is zero. Dark areas represents rim inflow zones in the previous model, but modeled as streams in the current ground water model.

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224. To assist in defining the relationship between stream flow and groundwater levels, the RGDSS Study also collected new information on stream and drain bottom elevations, stream channel geometry, and stream stage versus discharge relationships. *RGDSS Ground Water*

Model Documentation, Ch. 4, pp. 33 – 41. This evidence was also uncontested although Protestors' expert Charles Norris did suggest disagreement with the gradients specified for the RGDSS groundwater model by Eric Harmon.

C. Irrigated Lands Assessment, Ditch Service Areas and Land Cover Classification

225. The RGDSS Study evaluated the water use and consumption in the Valley. In order to determine the location and extent of groundwater withdrawals being used for irrigation and the location of native vegetation using groundwater, it was necessary to identify the irrigated lands in the Valley and the location of plant communities that could use groundwater. This work was performed by Agro Engineering, Inc. The work was completed in July 2000 and is reported in State's Exhibit No. 6 entitled *1998 Irrigated Lands Assessment Using Satellite Imaging in the Rio Grande Basin of Colorado*. The work was performed by or under the direction of the Proponents' expert Mr. Kirk Thompson, and the following Findings are based upon Mr. Thompson's testimony and reports. The work performed by Mr. Thompson was not factually disputed. It is nevertheless described in some detail since it is part of the foundation of the groundwater model which was disputed.

1. Irrigated Lands Assessment and Land Cover Classification

226. The irrigated lands assessment consists of essentially three components. The first component is a false color infrared image of Water Division No. 3, shown as Figure 8 in State's Exhibit No. 6. This image was based on Landsat satellite images taken in August 1998, and the underlying digital data was used extensively in the RGDSS Study. See generally State's Exhibit No. 6, pp. 12-21. *Transcript (Thompson) Vol. VI* p. 1047 ln. 12-23.

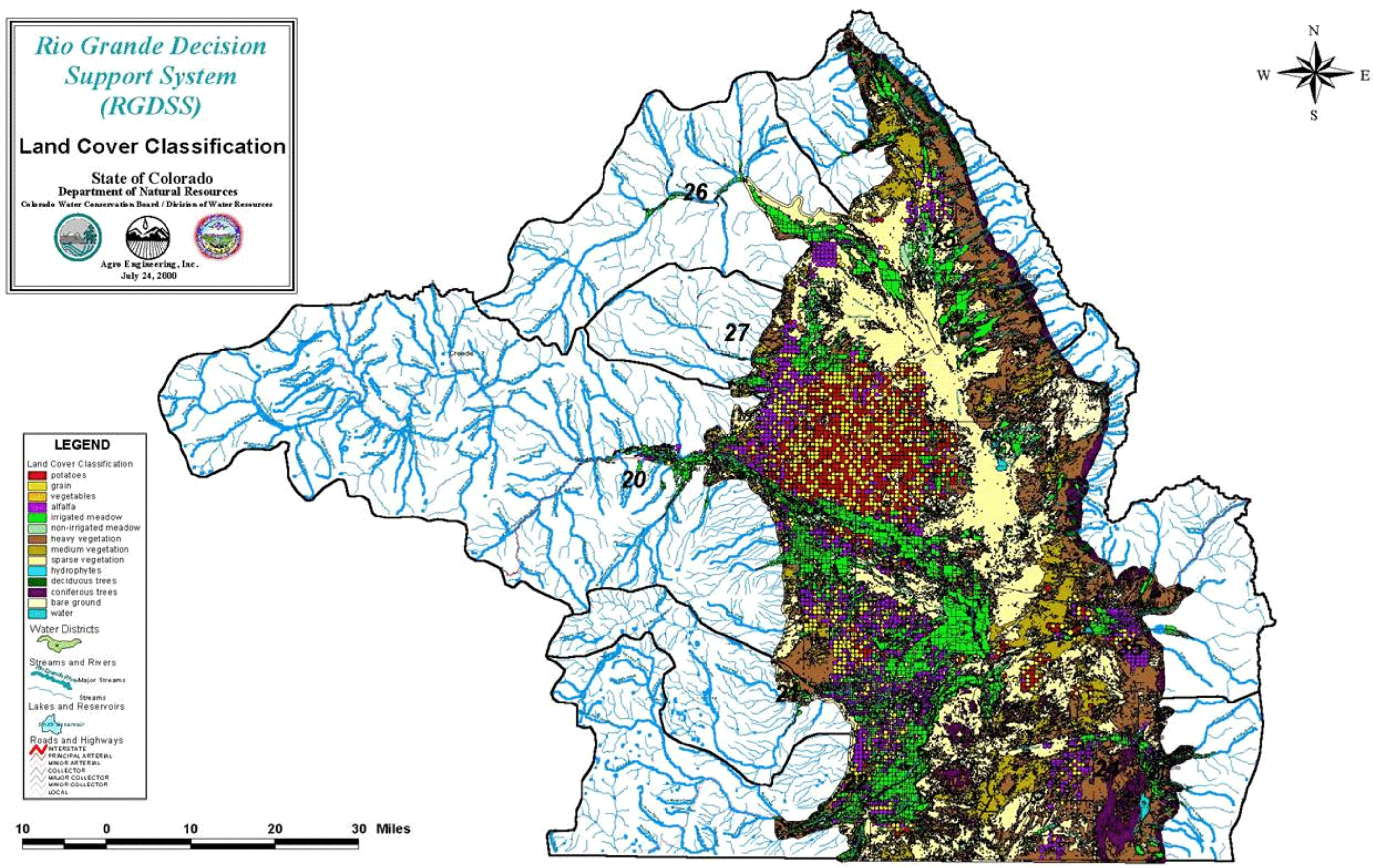
227. The second component is a land classification theme for the RGDSS groundwater model domain, which comprises the Valley's floor. The land classification theme has two parts, identification of irrigated lands and crop types, and identification of nonirrigated lands and the vegetative cover types. See generally State's Exhibit No. 6 at pp. 21-34. *Transcript (Thompson) Vol. VI* p. 1048 ln. 1-13.

228. The third component is the ditch-service-area theme. Agro Engineering identified the irrigation ditches in the Valley, mapped the ditches, and prepared a map showing the irrigated lands that could receive surface water from the various irrigation ditch systems in the Valley. See generally State's Exhibit No. 6 at pp. 7-11. *Transcript (Thompson) Vol. VI* p. 1048 ln. 16-23.

229. The vegetative land classification relies, in part, upon the "spectral signature" of the vegetative cover on the land. The "spectral signature" is derived from the data collected by the Landsat satellite, which consists of reflected solar radiation in the visible (red, blue, green) wavelengths, the "near" and "middle" infrared wavelengths, and thermal infrared wavelengths. State's Exhibit No. 6, Table 2. This spectral or wavelength data is then "classified" using the "maximum likelihood classifier" to identify areas of land with similar "spectral signatures."

230. Once areas with similar spectral signatures were identified, then certain "training sites" were selected that represented a specific type of vegetative cover. For example, fields where

potatoes were grown were used to "train" a computer algorithm to identify lands with that type of spectral signature as potatoes. This "training" was used for all major crops grown in the San Luis Valley and for the various types of nonirrigated vegetation in the San Luis Valley. The result of this process was a series of highly accurate maps showing the location of irrigated and non-irrigated lands and, for the irrigated lands, identifying the crops grown in 1998, and for the non-irrigated lands, showing the vegetative cover classification. A composite of the results of this work is shown in Figure 11 of State's Exhibit No. 6, seen below. It is also referred to as State's Exhibit 115A. *Transcript (Thompson) Vol. VI* p. 1086-88. The digital version of this exhibit and its related exhibits can be enlarged and provide fine detail of the various classification depicted.



231. Since the crop type and irrigated acreage data were used in the "State-CU" model (see paragraph 258, below) to determine the consumptive use of irrigation water, it was important that this work be as accurate as possible given the available data. Therefore, the classification of irrigated lands and crop type was verified and refined by cross-referencing the computer generated crop classification with records of crops grown maintained by the Rio Grande Water Conservation District (230,000 acres), the records of Agro Engineering for its clients' fields (30,000-45,000 acres), through interviews with vegetable growers, and through public meetings with growers. This process improved the accuracy of the crop classification.

232. The number of acres of irrigated land and the number of acres of each crop were also refined. The Landsat satellite data has a measured picture element (pixel) of 25 meters by 25

meters. Because Agro Engineering found this level of resolution to be too coarse to allow precise identification of field boundaries, it acquired satellite imagery of the irrigated lands in the San Luis Valley from the Indian Remote Satellite. This imagery has a spatial resolution of 5 meters by 5 meters and therefore allows a much more precise identification of parcel boundaries. Using this data, Agro Engineering separately identified and measured 10,213 irrigated parcels containing 612,739 acres of irrigated land. State's Exhibit No. 6, Table 6.

Table 6. 1998 Irrigated Acreage within the Basin

Irrigated Crop Classification	Number of Irrigated Parcels	Irrigated Acreage
Potato	732	80,064
Small Grain	1,424	114,214
Vegetable	81	7,583
Alfalfa	3,677	139,502
Irrigated Meadow	4,299	271,376
TOTAL	10,213	612,739

233. The land cover classification for nonirrigated vegetation was broken down into (1) water surfaces such as lakes and reservoirs; (2) nonirrigated meadows; (3) hydrophytes; (4) heavy native vegetation; (5) medium native vegetation; (6) sparse native vegetation; (7) bare ground; (8) deciduous trees; and (9) coniferous trees. Examples of and the location of these various land cover types in the San Luis Valley are shown in State's Exhibits No. 115A-115J. This classification scheme was used in the RGDSS groundwater model in conjunction with other data to assist in determining whether, where, and at what rates, nonirrigated vegetation consumed water from the groundwater table. A summary of all of the land cover classifications, the number of parcels and the number of acres of each are contained in Table 8 of State's Exhibit No. 6 and in State's Exhibit No. 115K.

Table 8. Land Cover Class Statistics within Ground Water Model Area

Land Cover Class	**Number of Parcels**	**Total Acreage**
Potatoes	732	80,060
Small Grains	1,424	113,541
Vegetables	81	7,583
Alfalfa	3,652	136,729
Irrigated Meadow	4,134	255,373
Non-Irrigated Meadow	7,597	97,591
Heavy Native Vegetation	14,810	425,322
Medium Native Vegetation	8,009	193,712
Sparse Native Vegetation	12,847	530,680
Bare Ground	2,993	45,294
Deciduous Trees	5,201	37,810
Coniferous Trees	1,641	58,862
Hydrophytes	916	2,642
Water	55	3,662
TOTAL	64,092	1,988,861

Exhibit 115A, printed above at page 76, illustrates the presence of the various classifications and the boundaries of Water Division 3 and the boundary of the groundwater model. A total of 1,988,866 acres were classified by this study. *Transcript (Thompson) Vol. VI* p. 1113 ln. 13. See Table 8, directly above.

2. Ditch Service Areas

234. The third component of the irrigated lands assessment included the preparation of a map showing the lands served by each of the irrigation ditches in the San Luis Valley. The location of irrigated lands and whether the land is irrigated with surface water, groundwater, or both, is important to understanding and modeling water use and consumption in the San Luis Valley. In order to allocate consumptive use of water between surface water and groundwater, it is also necessary to know what lands are served by what water rights and the amount of water available under the priorities of the water rights decreed to a given ditch. The process used to prepare the map of the irrigated lands was the collection of existing maps of ditch service areas, interviews with water commissioners knowledgeable about ditch service areas, preparation of draft maps, and review of the maps with the growers and their consultants to refine the accuracy of the maps. This work was performed by Agro Engineering. *Transcript (Thompson) Vol. VI* p. 1114-17.

235. The resulting map, shown in Figure 3 of States Exhibit No. 6, also allows the identification of land served by more than one ditch. In that circumstance, the water available from each ditch was allocated proportionally to the land and thereby permits the assignment of consumptive use to all sources of surface water supplied to a given parcel of land. The availability of surface water to a given parcel was, in a subsequent step of the RGDSS Study, linked with the groundwater supply available for that same parcel. See generally State's Exhibit No. 25, *RGDSS Spatial Systems Integration Task 3.1 - Data Centered Ground Water Model*. The combination of surface water and groundwater was used to determine if sufficient water was available to meet the crop irrigation requirements. According to the evidence, the available surface water and groundwater supply in the RGDSS model domain was sufficient to meet approximately 80% of the crop irrigation requirement. The shortage occurred primarily on land irrigated with surface water only. This evidence was uncontested.

3. Crop Consumptive Use - Calibrated Crop Coefficients

236. To determine the amount of water consumed by irrigation of crops, it is necessary to know how much water is consumed by different crops. As explained by Mr. Thompson, there are a variety of different methods for determining crop consumptive use. The techniques range from relative simple methods to more sophisticated methods that require climatological data that, at least historically, has not been available in the Valley. Prior to the early 1980's, there is only sufficient climate data generally available in the Valley for use of the Modified Blaney-Criddle method for determination of crop consumptive use. It is an accepted method of calculating consumptive use. See *Transcript (Thompson) Vol. VI* p. 1141.

237. Starting in the early 1980s, Agro Engineering began collecting climatological data and conducting studies that allowed it to use more sophisticated and accurate methods for determining crop consumptive use. During the 20 plus years that Agro Engineering has been operating in the San Luis Valley, it has developed "Calibrated Crop Coefficients" for all of the

major crops grown in the San Luis Valley which it uses in conjunction with a Modified Hargreaves Radiation Method for calculation of consumptive use. See *Transcript (Thompson) Vol. VI* p. 1140.

238. Evapotranspiration or ET consists of the amount of water evaporated from the earth's surface or plant leaf surface and the amount of water transpired out of the plant's leaves in response to heat and energy. Modern techniques for estimating ET involve the calculation of ET for a reference crop, which represents the maximum atmospheric demand for evaporation and transpiration, and the multiplication of the reference ET by a crop coefficient for a specific crop. *Reference ET* is the ET calculated for either a short-vetch crop (well-clipped grass) or a long-vetch crop one-half meter tall, such as alfalfa. A *crop coefficient* is the ratio of a specific crop's potential ET to *Reference ET.* The crop coefficient varies from crop to crop and varies during the growing season. *Potential Crop ET* is the amount of water that can be evapotranspired by a well-watered crop. The *Irrigation Water Requirement* is Potential Crop ET reduced by the effective precipitation. Crop coefficients have been developed through research at various locations. A Calibrated Crop Coefficient represents the Potential Crop ET for a given crop over the growing season at a specific location and is represented by a curve that shows the Potential Crop ET over the various stages of crop growth over the growing season.

239. In the RGDSS Study, the State attempted to determine historical crop consumptive use for the period 1950 to 2002. Due to the lack of detailed historical climatological data, it was necessary to use the Modified Blaney-Criddle method for this purpose. To improve the accuracy of the Study, the standard crop coefficients for the Modified Blaney-Criddle method were adjusted to closely match the Calibrated Crop Coefficients developed by Agro Engineering. This is a widely used method and the Court finds that Agro Engineering's calibrated Crop Coefficients are accurate and reliable and that it was proper to use these Calibrated Crop Coefficients to adjust the standard crop coefficients used in the Modified Blaney-Criddle method. With this adjustment, the Modified Blaney-Criddle method, as used to determine crop consumptive use in the State-CU model, was capable of making accurate predictions of crop consumptive use. A more detailed explanation of this process and how the revised crop coefficients were used in the RGDSS Study is contained in State's Exhibit No. 5 entitled *Historical Crop Consumptive Use Analysis*. See also *Transcript (Thompson) Vol. VI* pp. 1142-1150.

4. Evapotranspiration from Groundwater by Non-Irrigated Vegetation

240. Evapotranspiration of groundwater ("ET_g"), by nonirrigated vegetation is a significant component of the water budget of the Valley. It is also an important part of the RGDSS groundwater model. How this ET_g is determined also plays a prominent role in the State Engineer's analysis of the impact of new or increased withdrawals of groundwater under the Rules. Thus, the Court will discuss the evidence on this topic.

241. The RGDSS Study and the RGDSS groundwater model draw upon research performed by David J. Cooper, Ph.D., and others to understand plant physiology and to quantify the amount of ET_g from the relevant plant communities. Dr. Cooper is an expert in plant ecology, plant physiology, hydrology as it relates to plants and plant communities, and in evapotranspiration functions of native plant communities in the Valley. Dr. Cooper has conducted extensive

research into the relationship between groundwater levels and nonirrigated plant communities in the Valley. He testified as an expert witness on behalf of the Proponents on the topics of ET_g by nonirrigated vegetation and the appropriateness of the methodologies used by the State to identify and predict the quantity of ET_g by nonirrigated vegetation in the Valley. His testimony was both credible and unrefuted, and his expert report setting forth his specific opinions is contained in State's Exhibit No. 10.

242. In 1995 the Rio Grande Water Conservation District hired Dr. Cooper to investigate which plant species in the Closed Basin of the San Luis Valley were phreatophytes, their maximum rooting depth, whether their roots extended to the "extinction depth" reported by earlier investigations, and the geographic distribution of these plant communities. Dr. Cooper explained that a phreatophyte is simply a plant that can root to the water table, but this does not mean that all phreatophytes use groundwater. He also testified that many plant species in the San Luis Valley, particularly rabbit brush and greasewood, are "facultative phreatophytes," which means they can use water from the groundwater table but do not have to do so. The primary plant species that are phreatophytes in the Valley are rabbit brush, greasewood, alkali sacaton, and salt grass. As seedlings these plants rely upon rain or snowmelt for their water supply. As these plants mature they develop roots that extend to the water table enabling them to use groundwater, but they do not necessarily have to use groundwater. He further explained that "soil water," that is precipitation, has more oxygen and more nutrients and is less salty than groundwater. This makes the soil water a more desirable source of supply for plants in many cases.

243. The initial phase of Dr. Cooper's research consisted of digging deep trenches to the water table at 20 locations into the San Luis Valley and examining the rooting depths of the plants and where the root mass was located with respect to the water table. He next collected soil columns from the surface to the water table and washed the fine roots out of the soil sample. The fine roots are the plant roots that are active and provide an indication of where the main water absorbing capacity of the plants is located. From this Dr. Cooper learned that the bulk of the fine roots were not down near the water table but, instead, were located within the top foot and one-half of soil. Based upon this evidence, Dr. Cooper concluded that these plants are very well adapted for use of soil water, and do in fact use that water during some part of every year. *Transcript (Cooper) Vol. VII* p. 1056. ln 1-8.

244. Based upon his work, Dr. Cooper also concluded that the previously reported extinction depth, the depth below which phreatophytes were unable to root, was incorrect. The previous investigators had assumed an extinction depth of 12 feet, but in his deepest excavation Dr. Cooper found roots extending to the water table at 17 feet. *Transcript (Cooper) Vol. VII* pp. 1055-56.

245. Dr. Cooper also investigated the vegetation at each site to determine the plant cover, the abundance of the plants, which species were present, and their leaf area. He anticipated that the leaf area of the plants would decline as the water table declined. His research disclosed, however, that leaf area did not necessarily correlate with water table depth. From this he concluded that there are several factors other than groundwater levels that can control the vigor and health and therefore the leaf area of these plants. For example, he found that soil salinity greatly inhibited plant growth even in areas of high water tables, and that plant growth was

inhibited in coarse-textured soils with very poor water-holding capacity. Thus, it was Dr. Cooper's opinion that water table depth was just one of three or four environmental factors that can control and influence the composition of the plant community and its leaf area and, therefore, its evapotranspiration. *Transcript (Cooper) Vol. VII* p. 1056. ln 9-25; p. 1057 ln 1-3.

246. Dr. Cooper's work also involved several years of direct measurement of ET at 12 sites in the Valley. These measurements were carried out using elaborate and expensive scientific equipment referred to as a Bowen Ratio System. The data collected was analyzed to determine total ET by plants at each site, which was then reduced by precipitation to arrive at ET_g. Based upon this work, Dr. Cooper concluded, among other things, that the total ET for the plants at the sites he investigated were lower than the ET reported for similar plant communities elsewhere in the United States, and were lower than reported by previous investigations in the Valley. Dr. Cooper also concluded that wetlands have a much higher ET_g rate than non-wetlands; and while wetlands are a fairly small portion of the Valley, they use a large quantity of groundwater. With respect to wetlands, Dr. Cooper explained that when the water table is drawn down below the relative shallow rooting depth of wetland plants, they die back and if not re-wetted will disappear completely.

247. Dr. Cooper's work was utilized in the RGDSS Study to establish the areas in the Valley where phreatophytes are located. Dr. Cooper testified that by inspecting the plant communities in the San Luis Valley on foot or by airplane, both of which were done by Dr. Cooper, it is possible for a trained ecologist to identify the areas in the Valley where phreatophytes are located. This was the process used by the State and its consultants to develop the ET_g boundary used in the RGDSS groundwater model. The location of that boundary was uncontested.

248. With respect to the nine land cover classifications developed by Agro Engineering, it was Dr. Cooper's opinion that coniferous trees were properly excluded because, for the most part, those types of trees do not use groundwater. Dr. Cooper also testified that the classifications for water, hydrophytes and wet meadows should be combined because they are all essentially wetlands and have the same high ET rates and ET_g functions. He recommended that the categories of heavy, medium, sparse native vegetation, and bare ground remain the same. It was Dr. Cooper's opinion that these classifications were a good way to integrate the various environmental factors that influence plant growth and ET_g, and that they were properly developed by Agro Engineering.

249. Based upon the data collected from the Bowen Ratio System, Dr. Cooper subsequently developed and recommended ET_g rates for these five categories for different depths to groundwater. Dr. Cooper's recommendations are contained in State's Exhibit No. 10. The final data developed by Dr. Cooper's research suggested that the ET_g curves in use in the June 2004 RGDSS groundwater model should be modified to reflect the results of his completed studies, and thereafter adjusted periodically as new data and refined understandings of the concepts become available.

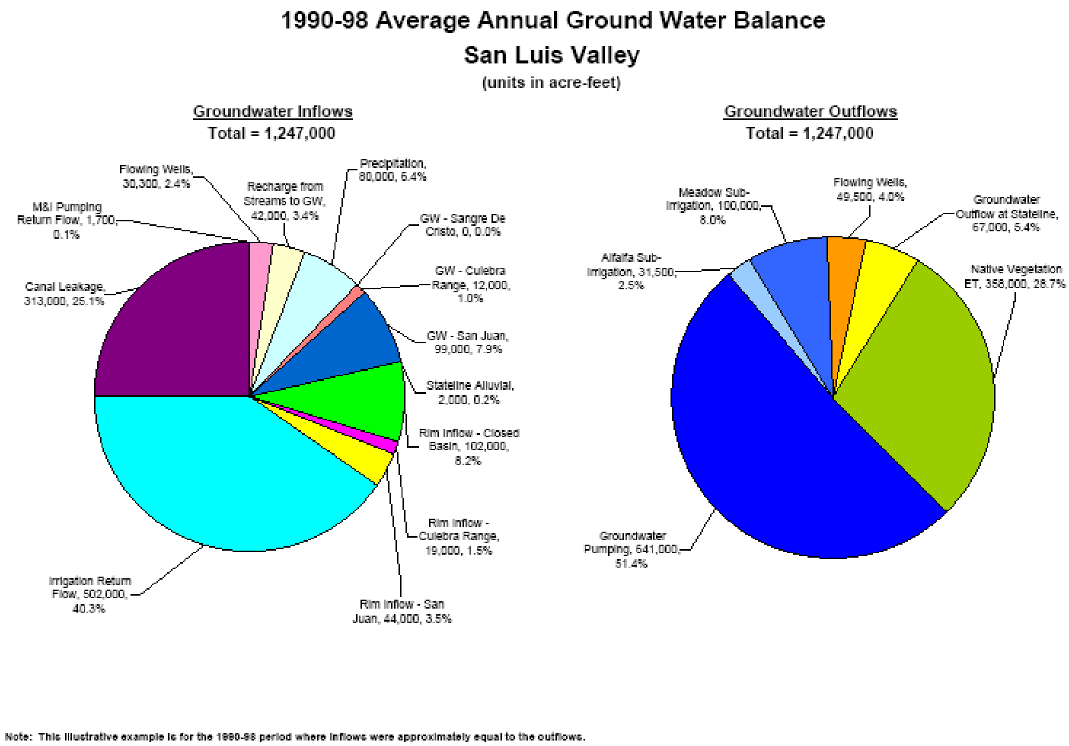
250. In summary, based upon the uncontested evidence, the Court finds that the State's identification of areas where phreatophytes are located in the San Luis Valley, the classification of those areas, and the ET_g curves for the various categories of phreatophytes used in the June 2004 RGDSS groundwater model and the revised curves recommended by Dr. Cooper are

scientifically valid and produce reasonable predictions of ET_g and the changes in ET_g for a given change in groundwater levels.

5. Groundwater Water Budget

251. Another important component of the RGDSS Study is the groundwater water budget, that is, the amount of groundwater that flows into and out of the groundwater model's domain. In order to accurately model the groundwater system, the inflows to and outflows from that system must be quantified. This water budget does not include all surface water, but does include the portion of surface water that reaches the groundwater aquifers. It does not include the surface flows that are consumed through irrigation or that flow out of the state.

252. The basic inflow components of the RGDSS groundwater model water budget include: (1) the amount of surface stream flow that seeps out of the streams into the underlying aquifers; (2) the amount of precipitation that reaches the aquifers; (3) the amount of subsurface groundwater flow into the model domain from the areas outside of the model domain; (4) the amount of so-called "rim inflow," the undiverted flow of small mountain streams that reaches the aquifers; (5) the amount of return flow from irrigation by either surface water or groundwater that reaches the aquifers; (6) the amount of canal or ditch losses that reach the aquifers; (7) the return flow to the unconfined aquifer from groundwater pumped from municipal and industrial wells; and (8) the amount of return flow from water discharged by confined aquifer flowing wells that reaches the unconfined aquifer. State's Exhibit No. 17, Table 1; State's Exhibits No. 117A – 117C; (State Exhibit 117C is below)



253. The basic outflow components of the RGDSS groundwater water model are: (1) water discharged from the confined aquifer by flowing wells and springs; (2) groundwater outflow into New Mexico along the southern boundary of the model domain; (3) evapotranspiration from groundwater by native vegetation (phreatophytes) and sub-irrigation of alfalfa and meadows; and (4) groundwater pumping. Stream gains from the groundwater table are reflected as negative numbers in the stream loss category of the groundwater water budget. *Id.* An overview of the water budget is contained in State's Exhibit No. 12 at pages 17-40. Exhibit RG 25 reflects these in the RGDSS groundwater model water budget.

RGDSS Groundwater Model Water Budget (acre-feet/year)

All values are annual averages for the period shown

	Period	No Pumping	Initial Period	Steady State	Avg Monthly	Monthly				
	Simulation	N4A00P13	I4A00P13	S4A00P13	A4A00P13	M4A00P13				
	Years	1990-1998*	1950-1969	1990-1998	1990-1998	1970-2002	1970-1979	1980-1989	1990-1998	1999-2002
Inflow	Flowing Wells Returns+	77,957	32,661	29,533	31,015	28,443	29,908	28,292	28,561	24,893
	Boundary Inflows	112,776	112,776	112,776	112,776	112,774	112,761	112,792	112,768	112,776
	State Line Inflow	1,191	1,330	1,349	1,366	1,321	1,334	1,320	1,308	1,322
	Wells Returns	1,818	1,024	1,818	1,818	1,723	1,584	1,715	1,821	1,868
	Precipitation Recharge	78,952	67,621	78,952	78,952	69,540	63,596	69,511	78,958	63,280
	Rim Recharge	164,330	144,268	164,330	164,329	165,585	153,582	196,160	164,330	121,977
	Irrigation Returns	362,478	443,942	501,854	501,854	470,811	437,837	490,138	501,854	435,081
	Canal Leakage	313,585	268,887	313,585	313,585	284,743	256,450	303,806	313,585	242,919
Outflow	Flowing Wells Outflow+	129,998	54,435	49,222	51,693	47,406	49,847	47,154	47,602	41,488
	Boundary Outflows	35,824	35,824	35,824	35,824	35,823	35,819	35,829	35,821	35,824
	State Line Outflow	32,481	29,187	29,898	29,676	29,064	28,980	29,002	29,213	29,098
	Wells Pumping	37,927	435,053	640,655	640,655	622,144	532,737	622,342	640,657	803,513
	Native ET	547,068	400,736	357,989	355,298	366,193	384,831	380,254	351,104	318,398
	Meadow Sub-irrigation	161,551	114,212	100,425	98,600	97,038	94,954	99,522	94,201	102,419
	Alfalfa Sub-irrigation	81,028	21,671	31,919	31,898	29,838	28,032	29,589	30,979	32,402
Net	Stream Gain	87,211	-18,770	-41,734	-35,281	-34,013	-20,709	-51,445	-31,839	-28,582
	Storage Change	0	0	0	-2,663	-58,387	-77,279	11,687	5,495	-330,082

Source: X4A00P13-bgt.htm

*1990-1998 hydrology is adjusted to simulate no agricultural pumping for the No Pumping period

+Flowing Wells are small capacity wells typically 2 inches in diameter and excludes larger capacity irrigation wells

Exhibit RG-25

254. As part of Mr. Harmon's geologic and hydrologic investigations in the San Luis Valley, he developed new estimates of the amount of groundwater that enters and leaves the model domain as groundwater flow. These estimates were based upon the application of Darcy's Law.[26] The procedure used and the results of the estimates are documented in RGDSS Ground Water Task 4 Memorandum, 2004, Ground Water Boundary Flow and Storage Changes, and the results are summarized in Table 3 of State's Exhibit No. 12. These estimates have a reasonable factual and scientific basis and were undisputed at trial.

255. Mr. Harmon also developed estimates of the amount of groundwater discharged by flowing wells and spring flows from the confined aquifer. The estimate of discharge by flowing wells required analysis of how those discharges had changed over time, due to the extensive "capping and valving" program undertaken by the Rio Grande Water Conservation District from

[26] Darcy's Law is a basic principle of groundwater flow and is shown in one formulation in Exhibit No. RG-6. Under Darcy's Law flow (Q) is equal to the hydraulic conductivity (K) times the hydraulic gradient (I) times the area (A). In other words, the flow rate of groundwater through a porous medium is proportional to head loss and inversely proportional to the length of the flow path.

1974-1983. That program greatly reduced the number of "uncontrolled" artesian wells and their resulting discharge from the confined aquifer. Mr. Harmon's estimate of discharge by flowing wells and springs is based upon the best available historical and current data and was not contested at trial. The procedures used and the resulting estimates are documented in RGDSS Ground Water, Task 17 - Drains, Springs & Flowing Well Data, are summarized at pages 25–30 of State's Exhibit No. 12 and were uncontested.

256. Another important component of the groundwater water budget is the rim-inflow from the streams around the perimeter of the Valley, which accounts for approximately 13 percent of the inflow to the groundwater system. See State's Exhibit No. 1, App. O, Table 19; State's Exhibit No. 117D (displayed above). As previously described, in order to improve the estimates of rim-inflow, as part of the RGDSS Study, 11 new stream gages were installed on rim streams in the San Luis Valley. The data collected from these new gages along with the available historical data was used to develop better estimates of rim recharge from both gaged and ungaged rim-inflow streams.

257. The largest inflow and outflow components of the groundwater water budget are those resulting from irrigation practices in the San Luis Valley. The inflow to the groundwater system from irrigation comes from two primary sources – canal or ditch loss and irrigation return flows. The largest outflow from the groundwater system is groundwater pumping.

258. The RGDSS Study required identification of the irrigated lands in the San Luis Valley, identification of the sources of water used to irrigate the land, estimates of the types of crops grown on the land, the irrigation water requirements of the crops, the method of irrigation used and whether the method changed over time, an estimate of the efficiency of the irrigation method, determination of crop consumptive use, the location and length of the ditches used to deliver water to the land, and the type of soils the ditches flowed across. See generally *Transcript (Slattery) Vol. VIII* at p. 1524 - 1587.

259. This information was integrated into 397 separate water budgets for ditch systems within the San Luis Valley. The function of the ditch water budgets and how they were used to calculate inflow into the groundwater system are illustrated in State's Exhibits No. 117A and B, and were explained in the testimony of James Slattery. *Transcript (Slattery) Vol. VIII* at pp. 1524 – 1545; 1549 - 1556. In this process of integration, the amount of surface water used for irrigation was separated from the amount of groundwater used for irrigation based upon the assumption that an irrigator with access to both surface water and groundwater would use groundwater to meet the crop irrigation requirement to the extent surface water supplies were not available to meet this need. Based upon the testimony of Mr. Ray Wright, Mr. Roy Helms, and Mr. Kirk Thompson, this appears to be a reasonable and reliable assumption so long as groundwater levels do not decline to the extent that wells cannot produce sufficient groundwater to meet this need. Based upon the testimony of Mr. Thompson, it appears that groundwater supplies remained adequate to meet the need of existing water users at least until 2002.

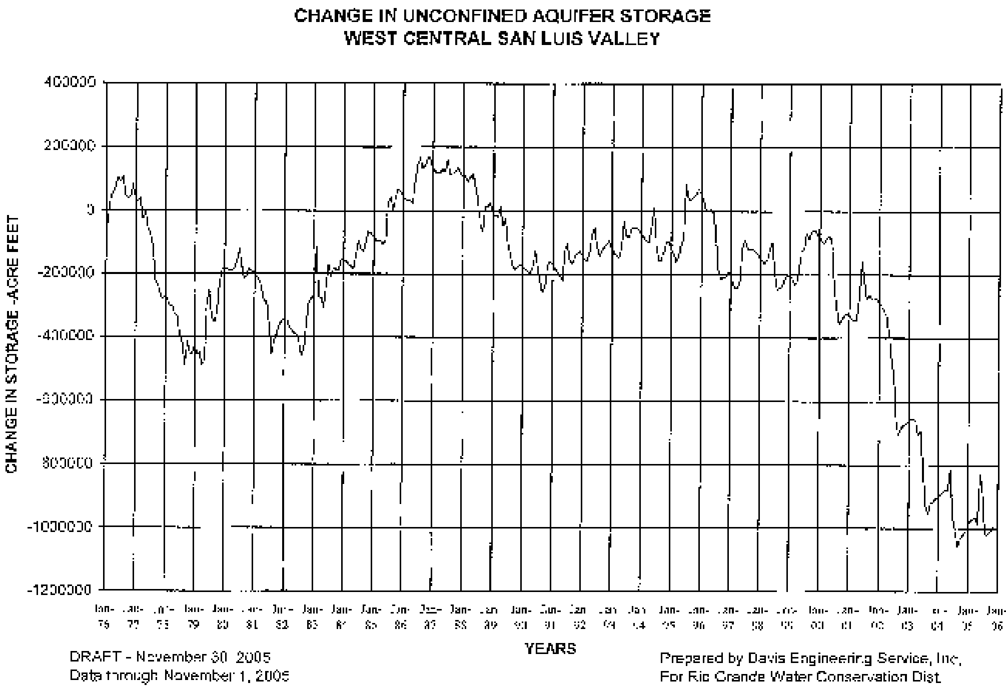
260. The water budgets for the ditches are part of the State-CU (consumptive use) Model. The State-CU model processes the water budgets and then provides input for the RGDSS groundwater model. See generally *Transcript (Slattery) Vol. VIII* at p. 1524, ln. 15 – p. 1527, ln. 4. This model is used, in part, to predict the amount of groundwater pumping. For example, for

2002 the RGDSS groundwater model predicted 936,249 acre-feet of irrigation pumping, an increase of some 300,000 acre-feet over previous levels. The Protestors challenged the reliability of this number and also pointed out that such increased withdrawals would be inconsistent with the moratoriums on new wells imposed by the State Engineer and would represents an illegal increase in groundwater use.

261. As many witnesses explained, 2002 was the driest year of record in the San Luis Valley; average temperatures were 30% above normal and stream flows were 75% below normal. The higher temperatures increased the crop irrigation requirements, and the decreased stream flow meant that irrigators had to use more groundwater to meet the increased crop irrigation water requirements. Under these conditions, it is reasonable to expect that groundwater usage would have increased substantially in 2002 and the evidence received supports this estimate.

262. The evidence indicates that irrigators with access to groundwater were able to meet their crops' irrigation water requirements in 2002 for two principle reasons. First, as explained by Mr. Thompson, irrigators pumped their wells longer than they would have pumped them under more typical climatic conditions. Second, many irrigators had decreed and/or permitted wells on the sides or corners of their fields that were placed back into service in 2002 to assist in meeting the crops' irrigation requirements. The existence of these wells and their use in 2002 is supported by the testimony of Mr. Vandiver, Mr. Davey, Mr. Helms, Mr. Wright and Mr. Thompson. In addition, the large increase in groundwater usage in 2002 is corroborated by the measured decline in groundwater storage that occurred in 2002, as documented both by the RGDSS groundwater model and the water level measurements and aquifer change in storage calculations made by Mr. Davey. See for example, State's Exhibit No. 83, reproduced below. And, after 2002 when surface water flows improved, the predicted groundwater pumping declined, as did the rate of decline in groundwater storage. *Id.* Thus, while the precise amount by which groundwater pumping in the Valley increased in 2002 is not known with certainty, the prediction made by the RGDSS groundwater model appears to be a reasonable estimate of that quantity given the assumptions made in the ditch water budgets and the evidence of resulting groundwater level declines. The testimony showed that this drastic decline in the unconfined aquifer in 2002 is mirrored by equally striking reductions in artesian pressure in the confined aquifer with heads falling dramatically in 2002 and not recovering as of the time of trial.

263. The amount of water in storage in the unconfined aquifer has changed significantly since the 1950s. This is in good part a result of the improved farming practices but as evident in State Exhibit 83, reproduced below, it is also a reflection of the current drought period.



264. As described above in paragraph 197 on page 67, Phillip Emery estimated that there might be as much as 2 billion acre feet of water in storage in the confined aquifer. Eric Harmon unequivocally rejected this “back of the envelope” estimate. Harmon described how Mr. Emery made the estimate and why it is grossly in error given the understanding of the hydrogeology described in these Findings. See *Transcript (Harmon) Vol. III* p. 527-531. The RGDSS estimates that less than 1 billion acre feet are in the entirety of the confined aquifer and that below 3000 feet the water quality degrades very rapidly because it contains high concentrations of dissolved salts. *Transcript (Harmon) Vol. III* p. 530 ln 21-25, p. 531 ln 1-7. Because the estimate of Phillip Emery was incorporated into a finding by the water court in the judgment in W-3466 (1975 Rules case), and was included in the findings of the Supreme Court in *Alamosa-La Jara Water Users Protection Ass’n v. Gould*, 674 P.2d 914, 929 (Colo. 1984), it is particularly important to emphasize that current hydrogeologic evidence reveals the amount in storage is less than one half what was believed to be true at the time of the first rules trial, and that there are significant water quality concerns as detailed by Mr. Harmon.

265. The RGDSS groundwater model also quantifies return flows from the pumping of municipal and industrial wells. Many of these wells pump from the confined aquifer, but all return flows go to the unconfined aquifer or are discharged into surface streams. See State’s Exhibit No. 12 at p. 25; State’s Exhibit No. 17, Table 1. The June 2004 RGDSS groundwater model incorrectly assigned the return flows from these wells to the model layer from which the well withdrew water. This error was corrected in the subsequent version of the model and tests have confirmed that the error in the location of return flows for this relatively small quantity of water has no meaningful impact on the reliability of the June 2004 RGDSS groundwater model. *Transcript (Schreüder) Vol. XXV* at p. 4768, ln. 24 – p. 4770, ln. 1.

266. The remaining significant inflow component of the groundwater water budget is precipitation recharge on the Valley floor. This component is distinct from the precipitation that reaches surface stream flows. It is the quantity of precipitation that percolates through the soil to the underlying aquifer. The quantity of this recharge varies both areally and temporally. The amount of recharge reaching the water table takes into account the vegetative cover of the land, whether the water is used by vegetation, including crops, or goes into soil moisture storage. Only the amount not consumed by vegetation or held in soil moisture storage is accounted for as an inflow to the groundwater system. An example of the areal distribution of the fraction of the precipitation that is inflow to the groundwater model is shown in Exhibits No. RG-13 and RG-14, and the relationship between elevation and precipitation in the San Luis Valley is shown in Exhibit No. RG-15.

267. The remaining component of the outflow portion of the groundwater water budget is ET_g by hay meadows, alfalfa, and native phreatophytes. ET_g by phreatophytes is the second largest outflow in the water budget. It is quantified using the vegetative cover classifications developed by Agro Engineering discussed above, the relationships between ET_g and depth to groundwater used in the RGDSS groundwater model, as supplemented by the ET_g data from Dr. Cooper's completed studies described above. The June 2004 RGDSS groundwater model did not include the ET_g versus depth-to-groundwater curves recommended by Dr. Cooper because that information was not available before June 2004. The ET_g versus depth-to-water relationships in the 2004 RGDSS groundwater model are shown in Exhibit No. RG-22 and are very similar to Dr. Cooper's recommendations. Dr. Cooper's recommended modifications to the ET_g versus depth to groundwater were made in the post-June 2004 version of the RGDSS groundwater model. The implementation of Dr. Cooper's recommendations resulted in a change of approximately 1% in amount of ET_g by phreatophytes computed by the RGDSS groundwater model. See *Transcript (Schreüder) Vol. X* at p. 1890, ln. 5 – p. 1895, ln. 5.

268. The representation of ET_g by phreatophytes as a function of both vegetative cover type and the depth to groundwater is based upon the established scientific principle that different plant communities have different ET_g rates along a water table gradient. And, subject to the limitations on the accuracy of groundwater levels predicted by the RGDSS groundwater model discussed below, the use of these methods results in a scientifically reasonable estimate of ET_g by phreatophytes in the Valley.

269. The ET_g by alfalfa and meadows is determined in essentially the same manner as ET_g by phreatophytes. The relationships between ET_g and depth to groundwater for meadow grass and alfalfa are shown in Exhibit No. RG 21. The areas where these crops are grown in 1998 were determined by Agro Engineering. And, as with ET_g by phreatophytes, subject to the accuracy limitations discussed below, the use of these methods results in a scientifically reasonable estimate of ET_g by subirrigated meadows and alfalfa in the San Luis Valley.

270. In summary, the water budget for the San Luis Valley used in the RGDSS groundwater model is based upon extensive factual investigation, sound engineering judgments, reliable and established scientific principles, and provides reasonable estimates of the inflows to and the outflows from the groundwater system in the RGDSS model domain of the San Luis Valley, including the annual quantities of groundwater withdrawals. The water budget represents an

important step along the path to better understanding the water resources in the San Luis Valley. It will be modified many times, as will every aspect of the RGDSS as more data accumulates.

271. The order entered by this Court in 2005 CW 12 approved rules which require totalizing flow meters on all non-exempt wells in the San Luis Valley. This will provide important new and accurate data for the water budget. The Court approves the State’s effort to ensure that the database of information for the RGDSS and the RGDSS groundwater model improves over time through enhanced collection of data and monitoring.