IX. RGDSS Groundwater Model

272. Computational fluid dynamics is not taught in law school. During the course of the trial, the Court and attorneys struggled at times to understand the nature and mechanism of mathematical modeling. The phrase "All models are wrong, but some models are useful"[27] was identified as a wry expression among mathematicians and modelers reflecting the limitations and usefulness of models. Similarly, Albert Einstein said, "As far as the laws of mathematics refer to reality, they are not certain; and as far as they are certain, they do not refer to reality."[28] Both quotations alert us to the fact that the "solution" to a problem posed to the RGDSS groundwater model will not have the absolute certainty of the solution to a simple subtraction problem.

273. The Court heard extensive testimony concerning the development of the groundwater model as one part of the RGDSS. The Protestors objected to the admissibility of the groundwater model and requested a hearing pursuant to *People v. Shreck*, 22 P.3d 68 (Colo. 2001) and CRE 702. This was a trial to the Court. Given the need to establish the development of the conceptual model as well as the underlying database to be used by the groundwater model, it would have been incredibly inefficient to hold a separate hearing under *Shreck*. The Court therefore entered a pretrial order that it would integrate its analysis of the model under *Shreck* into this order. The Court heard extensive evidence from some of the modelers who developed the RGDSS groundwater model describing in detail the steps leading to the version of the model presented to the Court. The Court also heard from Protestors' experts who varyingly questioned whether the model was properly calibrated and verified. Each of the water engineers, hydrographers, and modelers who testified in this case is highly respected and each has a proven track record demonstrating their competence in their respective fields. There was no dispute that the various experts were qualified under CRE 702 to express the opinions they held on this subject.[29]

274. A groundwater model is necessary for the complete evaluation of any new application for withdrawal of water from the confined aquifer due to the complex geologic and hydrologic conditions in the Valley and the large number and complexity of factors that must be considered when making such an evaluation. A mathematical computer model is currently the only practical way for the State Engineer to perform this duty. *Transcript (Slattery) Vol. IX* at p. 1677, ln. 18 – p. 1679, ln. 5; *Transcript (Simpson) Vol. XVII* at p. 3202, ln. 12 – 20. The leap forward in ambition and potential

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[27] Box, G.E.P., Robustness in the Strategy of Scientific Model Building, in *Robustness in Statistics*, R.L. Launer and G.N. Wilkinson, Editors. 1979, Academic Press: New York.

[28] Quoted in J R Newman, *The World of Mathematics* (New York 1956); originally believed to be found in *"Geometry and Experience," January 27, 1921*

[29] That the experts disagree as to some critical aspects of the model and the state of the aquifers should come as no surprise since the modeling experts, lawyers, courts, law review articles and science journals cannot even agree if we are talking about a "groundwater" model, a "ground-water" model or "ground water" model. The Court will use "groundwater model."

usefulness of a mathematical computer groundwater model in comparison to the electrical analogue model[30] of the Rio Grande Basin presented in the 1970's by Phillip Emery is immediately evident as one reviews the exhibits and testimony. This effort seeks to apply state-of-the-art modeling techniques to the complexities of the Rio Grande Basin. As part of the RGDSS, the groundwater model is an essential element of an approach to water resource management based upon scientific investigation as the foundation for decision making.

275. A groundwater model is simply an effort to simulate mathematically the operation of a physical system. *Transcript (Slattery) Vol. III* at p. 1486, ln. 14 – 22. A groundwater model "describes the behavior of the system in terms of mathematical equations." *Transcript (Schreüder) Vol. IX* at p. 1746. The larger and more complex the physical system involved, the more difficult it is to build a groundwater model that can precisely simulate the behavior of that system. Conversely, the smaller and less complex the physical system involved, the easier it is to build a groundwater model that can precisely simulate the behavior of that system. And, all other things being equal, the greater the quantity of data available throughout the model domain, the more likely it is that the computer model will accurately simulate the behavior of the physical system. See generally *Transcript (Slattery) Vol. VIII* at p. 1499, ln. 16 – p. 1507, ln. 15.

276. The RGDSS groundwater model is based upon the U.S.G.S. computer model code or program known as MODFLOW. State's Exhibit 1, Ch. 2, p. 1. MODFLOW stands for "Modular three-dimensional finite-difference groundwater model" and is widely accepted and used in the scientific community to simulate the occurrence and movement of groundwater. It was first published by the U.S.G.S. in 1984 and has been periodically updated since that time. It is not the only finite-difference model[31] available, but is very widely accepted. In fact, all of the experts in this case have used models constructed with MODFLOW. During the development of Phases 2 and 3 of the RGDSS, MODFLOW 98 was used; but in Phase 4, the modelers used MODFLOW 2000 1.7 and MODFLOW 2000 1.10. These versions of MODFLOW 2000 are not "new models" but include small fixes and patches similar to the ones all computer users encounter with software such as Microsoft Windows XP or Adobe Acrobat.

277. The version of the RGDSS groundwater model presented to the Court is referred to variously as "Phase 4" or "P13," or more properly X4A00P13.[32] Work continued on the RGDSS groundwater model even as the trial proceeded.[33] Similarly, the

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[30] Emery, Phillip A., Patten, Eugene P., and Moore, John E. 1975, *Analog model study of the hydrology of the San Luis Valley, south-central Colorado:* Colorado Water Resources Circular 29

[31] A finite-difference model calculates head at the center of cells which subdivide the model domain. *Transcript (McDonald) Vol. XVIII* at p. 3407

[32] X4A00P13 uses "x" as a placeholder because there are steady state, average monthly, monthly and no-pumping variants on this groundwater model. The RGDSS Groundwater Model Water Budget (RG-25) is a good place to view the designations. For example, S4A00P13 is the steady-state version of P13. M4A00P13 is the monthly time step version.

[33] Dr. Schreüder testified that work on Phase 5 was proceeding using MODFLOW 2000 1.15.01 and that the U.S.G.S. had released a new standardized stream flow routing package which addressed the issues which had required special code be written by Schreüder for Phase 4.

development of the RGDSS surface water model was still continuing as this case went to trial. *Transcript (Bennett) Vol. XIV* at page 2580.

278. The operator of MODFLOW specifies the model domain and provides the input files to MODFLOW. The input files define the area covered by the model (the model domain), the hydraulic characteristics of the material in the model domain, and the inflows and outflows to the model domain, including all stressors acting on the system. When these inputs are combined with the MODFLOW model program the result is a groundwater model. To automate and process the data gathered concerning subjects such as consumptive use, stream flows, drains, pumping and evapotranspiration for input into the groundwater model, ancillary computer programs were used. There were three primary programs. The State-CU program was described at length by Mr. Slattery and Dr. Schreüder. It was developed as part of the Colorado Decision Support System and makes the consumptive-use calculations for input into the model. It estimates quantities such as well pumping, applied irrigation water, return flows, canal leakage. StatePP takes the calculations from StateCC and assigns them to specific parcels of land based upon the GIS information, and then distributes the assignment to specific cells in the model. ModEx is a program that takes the hydraulic conductivity and other material property assignments and translates them for input to MODFLOW. It similarly prepares stream flow information for input.

279. MODFLOW is an “open source” program with specific modules or ”packages” which represent common physical mechanisms which the groundwater modeler may want to simulate such as stream flows, diversions from streams, well pumping, recharge and evapotranspiration. It also has “solvers” or programs which run a series of calculations to try to solve the “problems” posed by the modeler in the form of linear equations. There are five standard solvers available to use with MODFLOW and all can be obtained at the U.S.G.S. website along with the core code and packages. There is no dispute concerning the validity or appropriateness of the core MODFLOW code, its standard packages or the solvers.

280. It is expected that those who work with MODFLOW will seek to improve the existing packages and to develop new packages and solvers. The modelers of the RGDSS groundwater model made additions to MODFLOW. Some were made to better represent the physical system of the San Luis Valley and others were made to assist in the efficiency of the model. *Transcript (Bennett) Vol. XIV* at p. 2586, ln. 15 – 21. It was necessary to represent circumstances where diversions “sweep the river” or divert the entire flow of the river. The modelers modified the stream package to allow it to represent this phenomenon. They improved the way in which the stream package represents stage discharges. The modelers also designed a “relax package” which prevented the accidental cell dry-out in isolated areas along the edges of the model. As explained by the modelers, a cell dry-out causes problems for the model. Code was also written to allow the production of a summary water budget for the basin as a whole. There were enhancements to the evapotranspiration package, Finally, the modelers used a procedure known as a “mass balance override” which will be discussed at length later in this opinion. *Transcript (Bennett) Vol. XIV* at p. 2586, ln. 11 – 25- p. 2587 ln. 1-24. It is disputed in this case whether the use of the “mass balance override” is a proper

modeling methodology. A mass balance override allows the modeler to "set the convergence criteria very tight and still get a converged solution, but with a much better mass balance in the process." *Transcript (Schreüder) Vol. IX* at p. 1771.

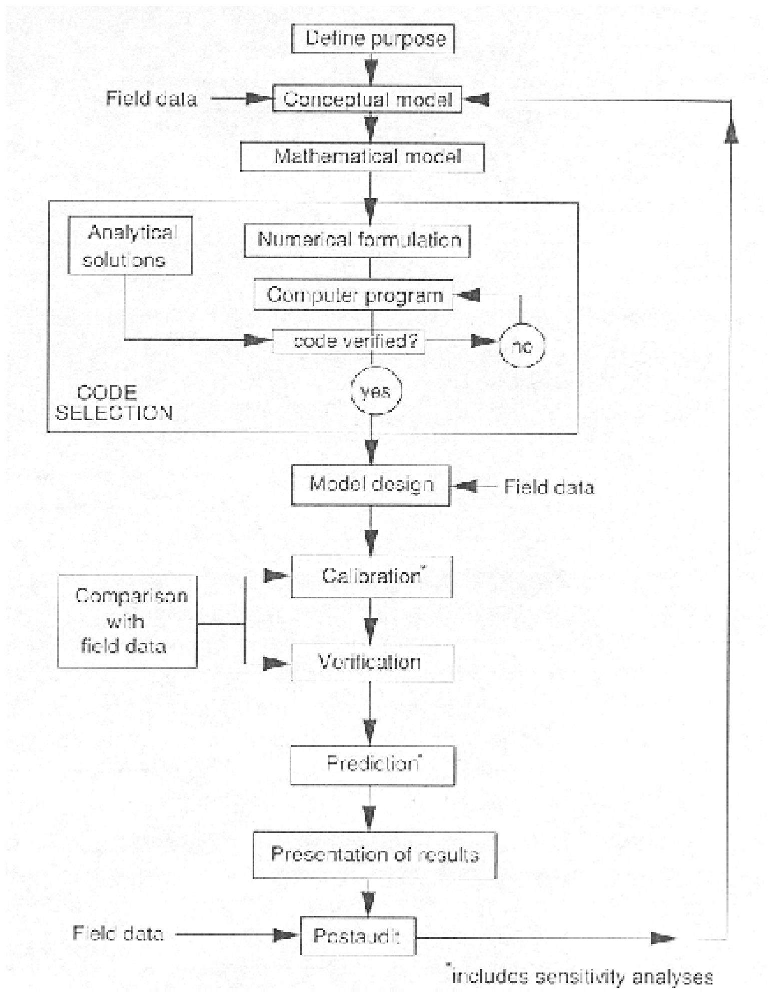
281. The State's work on the RGDSS groundwater model formed the basis for the U.S.G.S. publishing new stream and drain packages for MODFLOW that address modeling issues identified and solved as part of the RGDSS groundwater model. *Transcript (Schreüder) Vol. XI* at p. 1948, ln. 21 – p. 1949, ln. 10; *Transcript (Bennett) Vol. XIV* at p. 2588, ln. 10 – 15.

282. In MODFLOW the model domain is subdivided into three-dimensional blocks or cells and may include as many layers of blocks (cells) as the modeling task demands. The hydraulic characteristics of the aquifer system are supplied by the model, and then the model solves the groundwater flow equation, see Exhibit No. RG-7, for each cell in the model. Thus, the essential task performed by MODFLOW is to calculate the change in "head," the water level, in each cell in the model domain. And because MODFLOW is a finite-difference model, it calculates one water level per grid cell which represents the water level in the center of that cell.

283. The protocol for development of a mathematical groundwater model is generally agreed upon.[34] It begins with the definition of the study objectives, the development of a conceptual model and the selection of the core computer code or program. It proceeds to construction of the groundwater model, calibration of the model and performance of sensitivity analyses. The modeler then moves to predictive simulations, documentation of the study and a post-audit. The process then loops back to review of the conceptual model and renewed calibration. This is a simplification of a process which, as described in this trial, involved many back-and-forth discussions and adjustments of the conceptual model and the computer model based upon the field data. A schematic of the protocol is shown in Exhibit No. RG-4, taken from another text, Anderson and Woessner's book, "Applied Groundwater Modeling, Simulation of Flow and Advective Transport" (1992).[35]

[34] See, for example, *American Society of Testing and Materials (ASTM)* D-5447-93 "Application of a Ground-Water Flow Model to a Site-Specific Problem" (ASTM 1993)

[35] Anderson, M.P. and Woessner, W.W. (1992), *Applied Groundwater Modeling, Simulation of Flow and Advective Transport.* Eds. Academic Press, Inc. HarCourt Brace Jovanovich, Publishers, 38 pp.



Anderson and Woessner Modeling Protocol

Exhibit RG-4

284. Modeling begins by conceptualizing the problem or defining the purpose of the model in a “semi-quantitative description of what it is you want to model.” *Transcript (Schreüder) Vol. IX* at p. 1757. These concepts are then translated into mathematical equations. The model then tries to solve the problems represented by the equations. The modeler must then evaluate the solution or lack thereof by comparison to the real world, and then rethink the way the problem has been understood and represented. It is an iterative or trial and error process.

285. Good modeling requires a disciplined and realistic approach. It is more than merely stepping through the stages described by Anderson and Woessner. As Dr. Brendecke[36] described it:

[36] Dr. Brendecke is employed by Hydrosphere, the chief contractor on the surface water model of the RGDSS which is still in development. In 2003 he was retained by the Conejos Water Conservation District to monitor the RGDSS groundwater model for the district and to give technical advice to the groundwater modeling team as part of the peer review process. See *Transcript (Bennett) Vol. XIII* at 2382-83.

> I think there are a common set of steps or approaches or procedures, principles, if you will, that are common across a wide variety of modeling exercises. And these include a careful articulation of the purpose of the model; a realistic assessment of the data that are available to build the model and the limitations that might be inherent in that data; the development of new information if it's feasible, with respect for the time and resources available to build the model; a methodical process for creating the model that includes--that culminates in a calibration; and the documentation of the entire process.

Transcript (Brendecke) Vol. XIII at 2373.

286. In this case, the purpose of the model is to depict the movement of water into and out of the Rio Grande Basin aquifers, to depict the relationships between the aquifers, and to ascertain the effects of new withdrawals of groundwater from the Confined Aquifer System in the Rio Grande Basin in Colorado. The conceptual model is the hydraulic and geologic framework of the RGDSS groundwater model and the conceptual model has been described in some detail earlier in this opinion and in exacting detail in the RGDSS documentation. The mathematical model used to ascertain the effects of new withdrawals of groundwater from the Confined Aquifer System is MODFLOW and, since it is an established model code, the selection of the model code is inherent in the selection of MODFLOW. The model design was completed with the studies by Agro Engineer, Inc., Dr. David Cooper, and others who provided basic data on water-use practices in the Valley. The model was developed in stages or phases. Phase 1 was the feasibility study. The calibration and sensitivity analysis of the model was carried out in both Phase 3 and Phase 4, and the model was also separately verified in Phase 4. See section X B below; *Transcript (Schreüder) Vol. XI* at p. 2001, ln. 8 – p. 2004, ln. 14. Peer review was conducted throughout the development of the model. Predictive runs were made by the State, and those results were evaluated for reasonableness and reliability. Thus, the RGDSS groundwater model was developed following a generally accepted modeling protocol. See generally *Transcript (Schreüder) Vol. IX* at pp. 1759-65. See also American Society of Testing and Materials (ASMT) D5447-93, "*Application of a Ground-water Flow Model to a Site- Specific Problem*" Sections 4.1.1 through 4.1.8.

287. The model domain for the RGDSS groundwater model represents the unconfined aquifer and Confined Aquifer Systems of the San Luis Valley. See State's Exhibit No. 1, Fig. 4.3.1; State's Exhibits 113 and RG-8 presented below. RG-8 also shows the grid of cells one-half mile square.

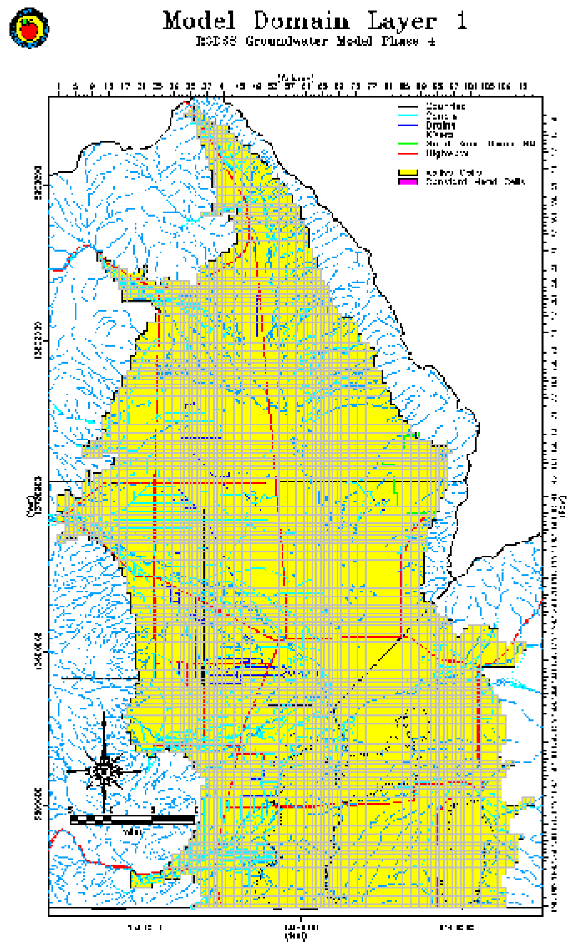
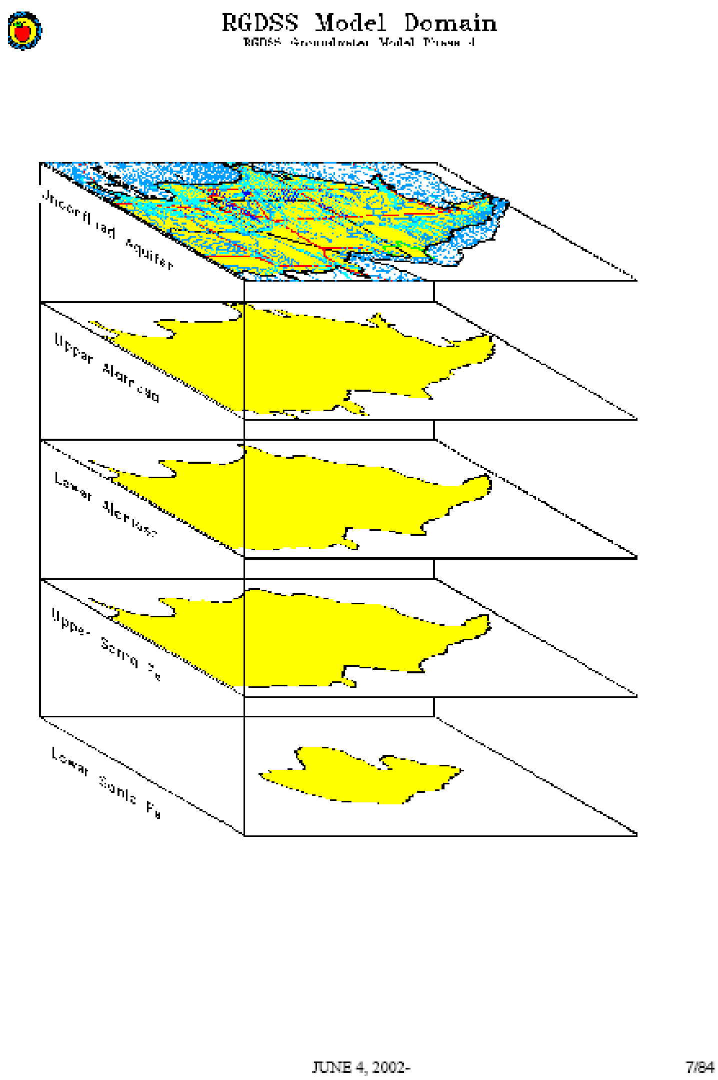


Exhibit
RG-8

288. The model has five layers corresponding to the geologic layers previously described. These are depicted in Figure 4.3.1 on the next page. The layers are also depicted in cross-sections in Task 32, Figure 35 of State's Exhibit No. 73 reproduced on page 64. The model has 51,015 active grid cells measuring one-half mile on each side. *Transcript (Schreüder) Vol. IX* at p. 1739. Layer 1 of the model is the largest with 12,431 active cells covering some 3,100 square miles or 1.98 million acres.[37] The model cells vary in thickness across the Valley.

[37] The size and complexity of RGDSS groundwater model was evident in listening to each of the experts describe the many other groundwater models they have worked on. For example, one of the largest models described by the experts is the Snake Plain aquifer model in Idaho. It is a MODFLOW 2000 application with a single layer, and 12,000 active cells one mile by one mile. See *Transcript (Brendecke) Vol. XIII* at 2364-65.

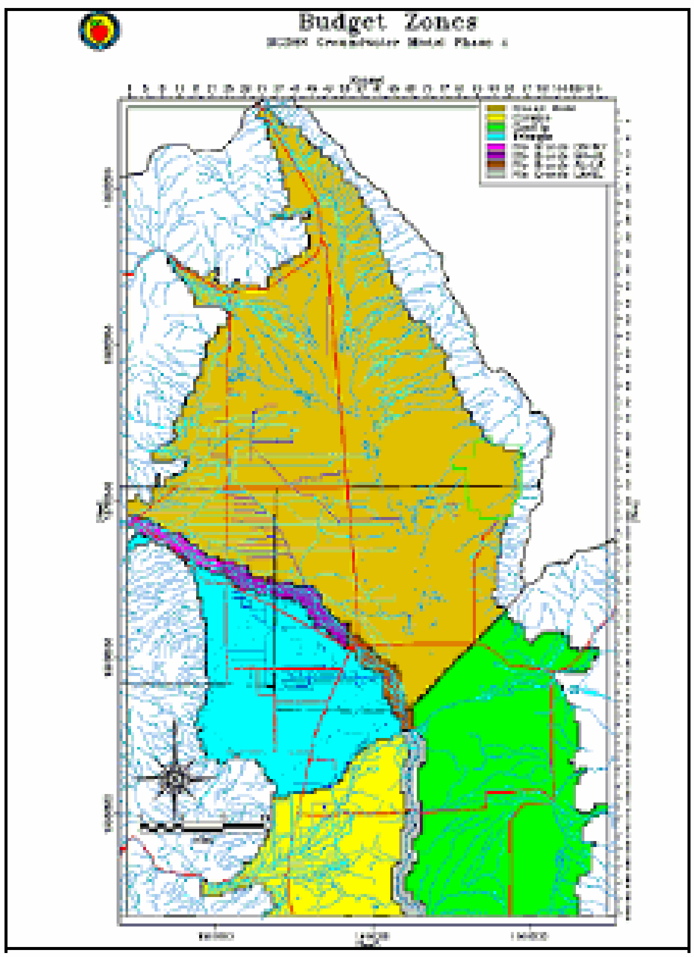
Figure 4.3.1



289. The initial hydraulic characteristics of the model layers were provided by Eric Harmon. See State's Exhibit No. 73, Figs. 1-34, based upon his extensive studies in the Valley. These values were subsequently adjusted during the model calibration process discussed below. The domain is divided into four zones because of the complex hydrogeologic conditions described by Mr. Harmon and others. Mr. Harmon provided his best estimates for the parameters such as hydraulic conductivities and storage coefficients but also provided a range within each zone which could be used for adjustments in the

calibration of the model without violating the basic conceptual model. Dr. Schreüder testified that he viewed the conceptual model here to have a "very, very strong foundation" from all of the studies of the San Luis Valley which culminated in the RGDSS. *Transcript (Schreüder) Vol. X* at p. 1838.[38] This is not to deny that there remain unknowns with regard to some areas within the domain which continue to create problems for the geologists and hence the modelers. State Exhibit 1, Figure 5.1.2.

Figure 5.1.2



290. The testimony of the various experts describing the many other small and large groundwater models with which they have been involved, shows the ambitious scope of this model. The small size of the cells, the complexity of the layers and the hydrogeology they represent together with the paucity of accurate input for key data such as the amount of pumping which has occurred over time, make development of this groundwater model a daunting task.

[38] Exhibits RG 13-23 offer selected representations of the parameters for some of the layers for some of the inputs and outputs illustrating how the groundwater model incorporated the known and estimated real world figures for the data essential to the model.

291. The inflow and outflows to the groundwater model are identified in the description of the water budget. In simplest terms, the groundwater model uses these inputs and then solves the groundwater flow equation and reports by how much groundwater levels or artesian pressures have changed in each cell in the model domain. It is also possible to have the model report a detailed water budget that shows changes to each inflow and outflow component of the groundwater model water budget. This, in turn, makes it possible to ascertain the nature of the impacts from new groundwater withdrawals within the model domain in the Valley.

292. In groundwater modeling there are two equations to calculate the groundwater flow. The first is the conservation of mass equation or mass balance equation. It is depicted in Exhibit RG-5. It is based on the formula:

$$\text{Input} - \text{Output} = \text{Change in Storage.}$$

293. The RGDSS groundwater model water budget is an expansion of this simple principle. The second equation used by the model is Darcy's Law. It is depicted in Exhibit RG-6. The formula is:

$$Q = kIA$$

Q is the flux. K is the hydraulic conductivity. I is the hydraulic gradient. A is the area. The model combines these equations to write a partial differential equation to describe the change to the various components. To solve for a variable such as hydraulic head, the model would apply the groundwater flow equation depicted in Exhibit RG -7 and below.

The Groundwater Flow Equation

$$S_C \frac{\partial h}{\partial t} = \frac{\partial}{\partial x}\left((h_t - h_b)k_{xx}\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left((h_t - h_b)k_{yy}\frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial z}\left(k_{zz}\frac{\partial h}{\partial z}\right) + V$$

- where

  h is the hydrailic head

  h_b is the aquifer bottom

  k is the hydraulic conductivity

  S_C is the storage parameter

  V is the volumetric source term

Exhibit
RG-7

294. The formula is described in detail by Dr. Schreüder. *Transcript (Schreüder) Vol. IX* at pp. 1784-98. The appropriateness of these formulas and the modelers' general application of them were uncontested.

295. The model calculates the change in storage and flux on a cell-by-cell basis and on a domain-wide basis in time steps or periods. The model calculates the flow through each of the six faces on every single one of the cells in a domain. The equation for each cell depends upon the heads in other cells. Mr. McDonald referred to the simultaneous solving of the equations for the faces of each cell in the domain for a given time step as a "system of simultaneous equations."

296. The groundwater model needs to calculate the mass balance by evaluating the stresses that act upon the aquifer in terms of the inputs and outputs gathered during the RGDSS development. RG-9 visually depicts this:

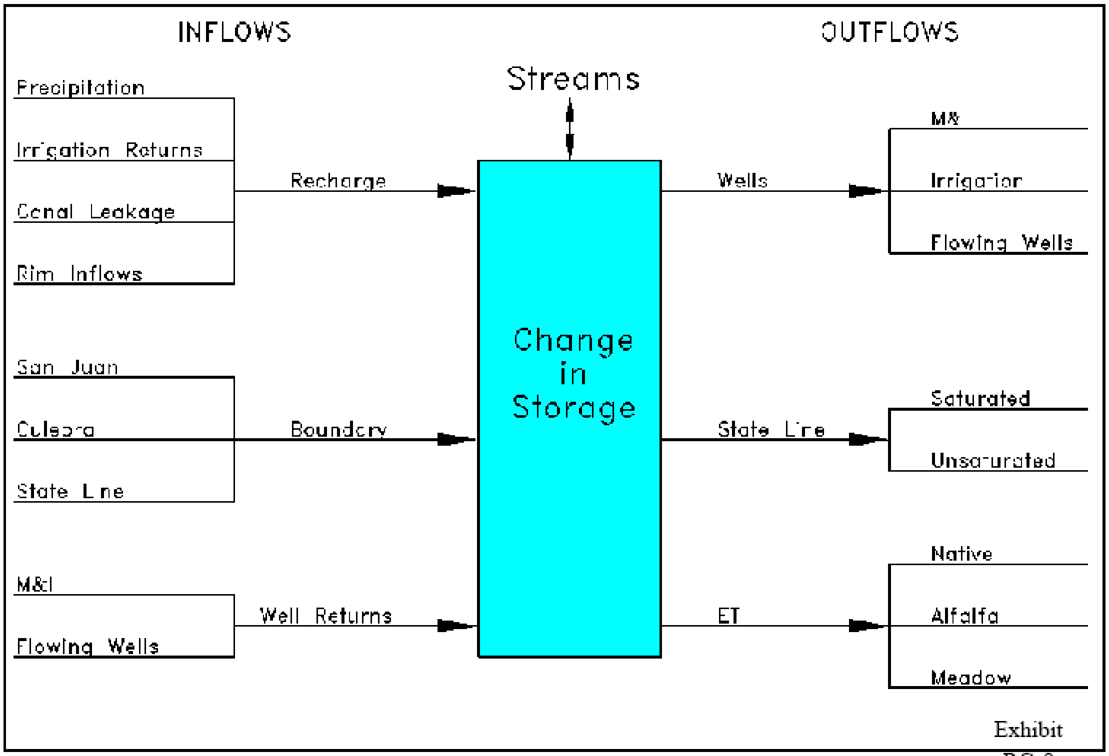
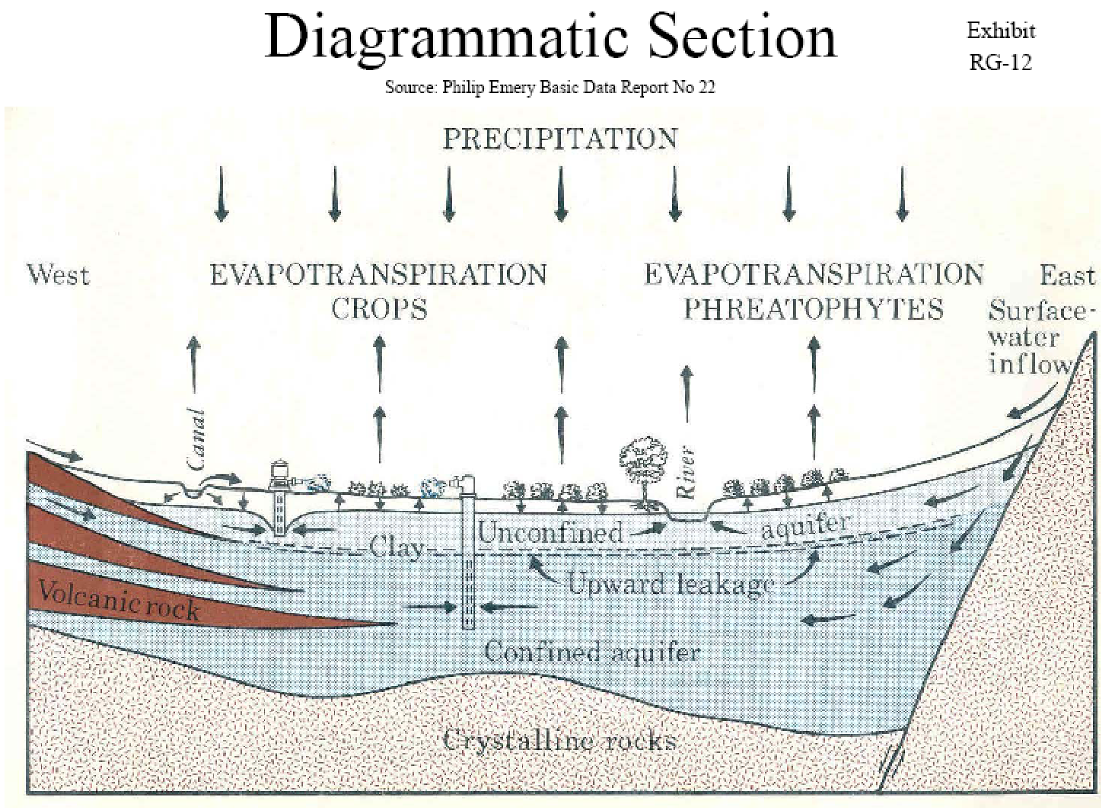


Exhibit RG-9

297. The study period originally chosen for the RGDSS was 1950-1997, but it was subsequently expanded to cover 1950-2002. The State developed both a steady-state model and a transient mode RGDSS groundwater model. A steady-state groundwater model assumes that the stresses on the groundwater system are constant year round and that there is no change in groundwater storage over the time period simulated. *Transcript (Slattery) Vol. VIII* at p.1493. Thus, by definition, any new use of groundwater would not reduce groundwater storage. The steady-state groundwater model uses the period 1990-1998 because this was a relatively stable set of years. *Transcript (Schreüder) Vol. X* at p.1917. Transient groundwater models, on the other hand, do not assume groundwater storage remains constant over the simulated period. Instead, they break the simulation period into a number of discrete time steps and solve the groundwater flow equations at the end of each time step. The transient mode RGDSS groundwater model uses monthly time steps with shorter "stress periods" within the month. *Transcript (Slattery) Vol. VIII* at p. 1498-99. It attempts to simulate the "true changes in the system through time." *Transcript (Schreüder) Vol. X* at p. 1923.

298. Dr. Schreüder chose an old illustration of Phillip Emery to illustrate some of the interaction between the inputs and outputs listed above. See also Protestors' Exhibit P-29, reproduced at page 38.



299. The decision whether a steady-state model or a transient model is appropriate depends, in large part, upon the characteristics of the system being modeled and the purpose of the model. A steady-state model is most appropriately applied for predictive purposes in a groundwater system where groundwater levels are fairly consistent and the stresses acting on the system are relatively constant over time. A transient groundwater model is more appropriate for predictive purposes in a groundwater system where groundwater levels vary significantly with time and/or where the stresses on the system are not constant over time. *Transcript (Slattery) Vol. VIII* at p. 1497, ln. 19 – p. 1498, ln. 18.

300. The evidence establishes that a transient groundwater model is more appropriate for predictive purposes in the San Luis Valley. See e.g. *Transcript (Slattery) Vol. VIII* at p. 1498, ln. 12 – 18; p. 1523, ln. 8 – 16; *Vol. IX* at p. 1682, ln. 16 – p. 1683, ln. 6; *Transcript (Schreüder) Vol. XI* at p. 1967, ln. 12 – 17. The major components of the groundwater water budget vary seasonally and annually. Leakage from canals only occurs during the irrigation season and is the greatest during the peak of the annual runoff when canal flows are at their highest; irrigation well pumping occurs primarily in June through August; and leakage from canals and irrigation well pumping vary annually depending on surface diversions and climatic conditions. Likewise, ET_g by

phreatophytes and subirrigated meadows and alfalfa occurs during the growing season but not during the winter months. And as shown by State's Exhibits No. 81.1, 81.2, 81.3 and 81.4, groundwater levels in the unconfined aquifer and artesian pressure in the confined aquifer vary considerably, both seasonally and annually. A steady-state groundwater model is incapable of showing the different effects of these seasonal changes and, therefore, all other things being equal, is not as reliable as a transient groundwater model for making predictions about the effect of new groundwater withdrawals from the confined aquifer in the Valley. *Transcript (Slattery) Vol. VIII* at p. 1493, ln. 5 – p. 1494, ln. 16; p. 1495, ln. 18 – p. 1498, ln. 18; *Transcript (Schreüder) Vol. XI* at p. 1967, ln. 12 - 17.

301. The RGDSS groundwater model used as the basis for the Rules was a transient groundwater model. It is the so-called Phase 4 model, because it is the version completed in Phase 4 of the RGDSS Study. At times during the trial it was also referred to as P13. While it is the transient P13 model more fully described as M4A00P13 that is presented by the State to support the Rules in question, the record, the experts, counsels' arguments and this opinion refer to the steady-state version of P13, or S4A00P13, as well as the average-monthly and the monthly transient versions. The entire group of versions together is referred to as X4A00P13, as already noted.

302. At the conclusion of Phase 3 of the RGDSS Study in early 2003, the State Engineer convened a peer review group and expert groundwater modelers, and asked them to critique and improve the RGDSS groundwater model. The peer review process lasted until June 2004 and resulted in additional data being collected to address shortcomings in the model, additional data analysis, additional calibration parameters, additional sensitivity analyses, refinement to the model's operation, verification, and extensive calibration efforts. *Transcript (Slattery) Vol. VIII* at p. 1485, ln. 8 – 17; *Transcript (Schreüder) Vol. XI* at p. 2007, ln. 17 – p. 2008, ln. 8; *Transcript (Brendecke) Vol. XIII* at p. 2385, ln. 24 – p. 2386, ln. 19. It is the transient RGDSS groundwater model that resulted from the peer review process that the State Engineer relied upon in preparing the Rules. *Transcript (Slattery) Vol. VIII* at p. 1515, ln. 24 – p. 1516, ln. 1.

303. As already noted, the State developed both a steady-state model and a transient model. The steady-state model covered the period 1990-1998, a period over which groundwater levels varied annually, but from the beginning to the end of that period there was little net change in storage. This steady-state model was not used for predictive purposes, but instead was used as a "stepping stone" to the transient groundwater model. *Transcript (Slattery Vol. VIII* at p. 1494, p. 19 – p. 1495, ln. 15. It was used for this purpose because trial simulations with the steady-state model could be completed in a matter of minutes as compared to the transient model that required 12 or more hours to complete a single simulation. The steady-state model was neither intended for nor appropriate for predictive use. *Transcript (Slattery) Vol. VIII* at p. 1523, ln. 8-16; *Transcript (Schreüder) Vol. X* at pp. 1923-28.

304. Because of this difference in the time required to run the two models, when the modelers wanted to test the effect of proposed changes to the model, they could quickly and easily test the effect of the changes using the steady-state model. If the results from

the steady-state model were reasonable and seemed to address the issue of concern, they would then implement the change to the transient model, make a simulation and evaluate its results. *Transcript (Schreüder) Vol. XI* at p. 1966, ln. 25 – p. 1967, ln. 11. Likewise, the modelers used the steady-state model to do sensitivity analyses; that is, to conduct tests to determine what parameters the model was most sensitive to, in other words, what types of changes to the input had the greatest impact on model predictions. This, in turn, enabled the modelers to identify areas where additional data was needed to improve the reliability of the model.

305. An important achievement of the study is the development of a basin-wide water budget. RG-25 represents the budget including steady-state, no-pumping, and transient runs. Of particular note, these support the testimony of others based upon the other data collected in the RGDSS indicating that there has been a loss of storage in the confined aquifer that amounts to mining the aquifer. The RGDSS Groundwater Model Water Budget shows the ability of the model to take the known information and estimations regarding the inputs and outputs diagrammed in RG-9 above and put them into a format that illustrates a downward trend in storage and in stream gain, which corresponds to the testimony of Mr. Davey and Mr. Vandiver, and the downward trends in stream flow found in Exhibits 102 and 103.

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