X. Protestors' Objections To and Criticisms of the RGDSS Groundwater Model

306. Since the Colorado Supreme Court announced *People v. Shreck*, 22 P.3d 68 (Colo. 2001), C.R.E. 702 has been the standard for admission of expert testimony. The rule provides:

> If scientific, technical, or other specialized knowledge will assist the trier of fact to understand the evidence or to determine a fact in issue, a witness qualified as an expert by knowledge, skill, experience, training, or education, may testify thereto in the form of an opinion or otherwise.

307. The determination of whether a witness is qualified to testify as an expert witness is committed to the discretion of the trial court and will not be disturbed absent a clear abuse of discretion. *Carder, Inc. v. Cash*, 97 P.3d 174 (Colo. App. 2003). In making this determination, a court must also necessarily find that the expert's proposed testimony is both relevant under C.R.E. 402 and not unfairly prejudicial under C.R.E. 403. *Tatum v. Basin Resources, Inc.* 2005 WL 3071564, (Colo. App. 2005). When deciding the admissibility of expert testimony, a Colorado court must make findings on the record that the testimony is (1) founded upon the scientific principles at issue which are reasonably reliable; (2) helpful to the trier of fact; (3) that the probative value outweighs any prejudicial effect under C.R.E. 403; and (4) given by a qualified expert. *Masters v. People*, 58 P.3d 979 (Colo. 2002). In making this determination, the Colorado Supreme Court has instructed a trial court to "consider a wide range of factors pertinent to the case at bar" and not restrict itself to any specific set of factors. There is no automatic requirement that a specific hearing be held on the reliability of the evidence. *People v. McAfee*, 104 P.2d 226 (Colo. App. 2004). In this case there was no jury, and the Court entered an order indicating it would evaluate the objections to the admissibility of the State's groundwater model during the trial. There was no dispute as to the qualifications of any of the experts who testified with regard to the groundwater model. The objection was to the admissibility of the groundwater model itself. To the extent the Protestors objected to the admissibility of the opinions of the Proponents' experts as to the validity of the groundwater model, the objections were not well taken under the provisions of the rule.

308. Protestors framed their objections to the groundwater model in terms of the modeling protocols already outlined. They specifically objected that the model does not converge, is poorly calibrated and has not been subjected to a properly documented sensitivity analysis. For these reasons, the Protestors generally argued the groundwater model is unreliable, at least for predictive purposes.

309. Evaluation of the RGDSS groundwater model involves review of the scientific principles underlying the model, a review of the reliability of the model, and the peer review process in its development. In this case, the Court was privileged to listen to many well-qualified experts who agreed that the general computer program for a finite-difference model and the associated modular components developed by the United States Geological Survey and generally known as "MODFLOW" is a generally accepted

standard computer program from which specialized models for predicting the flow of water in a basin or region or area have been developed. The experts universally agreed that MODFLOW is grounded "in the methods and procedures of science." See *Daubert v. Merrill Dow Pharms. Inc.*, 509 U.S. 579, 590 (1993). Of course, the fact that all parties agreed the basic MODFLOW program and models built using this mathematical program have been admitted into evidence in many trials and used by all the experts in this case in some manner is not the end of the inquiry. As discussed earlier in this opinion, MODFLOW provides a set of mathematical formulas which require individualized databases providing the particular geology and hydrology of the model. In general, as also noted, the conceptual model and the databases were not seriously challenged except for lack of actual data as opposed to estimates.

310. It is also important to remember that the fact that a state or federal agency has used a model in the past does not relieve the agency or party from continuing to evaluate the accuracy of a computer model, preferably by empirical testing, and to abandon or improve the model if shown to be unreliable. See *Sierra Club v. U.S. Forest Service*, 878 F. Supp. 1295 (S.D. 1993); *Ohio v. E.P.A.*, 784 F.2d 224, 226-31 (1986); *Natural Resources Defense Council, Inc. v. Herrington*, 768 F.2d 1355 at 1391.

311. The Colorado Supreme Court reviewed another groundwater model based upon the MODFLOW framework in *City of Aurora*, 105 P.3d 595 (2005). In that case the Supreme Court stated at 612-13:

> [I]n order for computer modeling results to be reliable, and hence relevant, for predicting the timing and amount of both depletions and exchange, the model must be operated in a manner that is consistent with accepted modeling techniques. If the model is operated in some other manner, there must be sufficient evidence that such other method produces valid and reliable results.

312. The Supreme Court went on to review the areas of the groundwater model which the water court had faulted the proponents for as follows:

> The water court then carefully analyzed the evidence as to the modeling techniques that PCSR's experts employed to operate the groundwater and surface water models used in this case. After noting the relevant techniques, the water court determined PCSR's[39] experts committed errors in technique with respect to the groundwater model because they failed to conduct a sensitivity analysis on the model, failed to properly calibrate the model, failed to explain anomalous results and residual errors, ignored another expert's report suggesting further evaluation, and failed to complete an independent peer review of the model.

[39] PCRS stands for Park County Sportsmen's Ranch

313. The objections of Protestors here echoed the arguments made by the State in opposition to the model proposed by PCRS in *Aurora*.[40] For the reasons stated below, the Court does not find the facts here to be anything like those in *Aurora*. The Court has assessed the reliability and relevance of the general scientific principles applicable to groundwater modeling, the methodology used in preparing the conceptual model, the gathering of the various database elements, the selection and modifications of MODFLOW, and the application of the theories and principles to the Rio Grande Basin. While the databases already described in depth above are far from complete or perfect, they are clearly the best available information. The experts on both sides employed "in the courtroom the same level of intellectual rigor that characterizes the practice of an expert in the relevant field." *Kumho Tire Co., Ltd. v. Carmichael,* 526 U.S. 137, 152 (1999). Here both the Proponents' and the Protestors' experts expressed opinions for which they could provide supporting evidence. "[I]t is critical that an expert's analysis be reliable at every step." *Amorgianos v. Amtrak,* 303 F.3d 256, 267 (2d Cir. 2002).

314. As noted in the *Reference Manual of Scientific Evidence, at 74,* "…science is, above all, an adversary process. It is an arena in which ideas do battle, with observation and data the tools of combat." Finally, there are no "analytical gaps" or leaps of faith in this groundwater model. See *Gen. Elec. Co. v. Joiner*, 522 U.S. 136, 146 (1997). The Court's ultimate conclusions about the use of the model are set forth below following a description of the contested aspects of the groundwater model.

A. Convergence of the Model and the Mass Balance Override

315. During the course of this trial, a significant disagreement between the experts revolved around proper methods and standards for determining if a model "converges." There was a substantial disagreement among the experts as to the relative importance of two important measures of a model's accuracy: convergence and mass balance. It also became apparent that what degree of convergence is adequate for a particular model is a matter involving professional judgment within the framework of the modeling standards described above. The technical appraisal of whether there is convergence is described below, but it is revealing that Dr. Schreüder initially described it as the iterative process by which the model "finds the answer to the problem as you posed it." *Transcript (Schreüder) Vol. XI* at p. 2009.

316. At trial, the Protestors' views were presented by their expert witnesses: Mr. William Hahn, Mr. Charles Norris, and Mr. Michael McDonald. Mr. Hahn and Mr. Norris both were of the opinion that the RGDSS groundwater model does not "converge" and, therefore, is unacceptable for any predictive purposes. Protestors' Exhibit No. P-1, Professional Opinion 2, pages 9-11. The Protestors criticized the reliability of both the 1990-1998 steady-state and predictive transient versions of the RGDSS groundwater model. The Protestors' experts did contend that because the steady-

[40] The State of Colorado opposed the admissibility of the groundwater model in *Aurora*, and Dr. Schreüder was a principle witness to the inadequate conceptual framework and that the MODFLOW application was not operated in a manner consistent with accepted modeling techniques.

state model is the foundation for the transient groundwater model, the transient groundwater model cannot be relied upon for any predictive purpose.[41]

317. Exhibit RG-11 is an example of the iterative process solving a problem for which we already know the answer. MODFLOW looks at the change in solution from one iteration to the next to measure convergence.

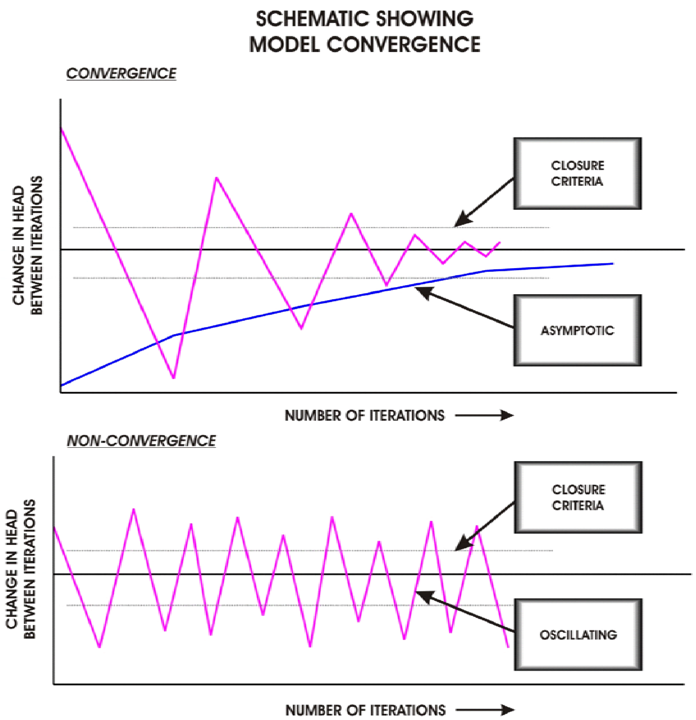
$$\text{Solving } x_{i+1} = \tfrac{1}{2}\,[x_i + 100/x_i]$$

i	x_i	x_i^2-100
0	1.000000000000	-99.000000
1	50.500000000000	2450.250000
2	26.240099009901	588.542796
3	15.025530119987	125.766555
4	10.840434673027	17.515024
5	10.032578510961	0.652632
6	10.000052895643	0.001058
7	10.000000000140	0.000000
8	10.000000000000	0.000000
9	10.000000000000	0.000000

Exhibit RG-11

Exhibit P-34 graphs the change in solution from one iteration to the next illustrating the concept of “convergence” as the groundwater model does a “run.”

[41] These criticisms notwithstanding, they did contend that the steady-state groundwater model can be relied upon to make predictions about the impacts of new withdrawals of groundwater from the confined aquifer system. At least they did rely upon it to contend that results of those predictions show that unappropriated water is available for withdrawal without injury to the vested water rights of others.



318. Mr. Hahn, Mr. Norris, and Mr. McDonald testified that convergence is a fundamental first step in solving groundwater modeling equations and reaching a solution. There is no dispute among the experts in this case that convergence is "a fundamental part of the entire process of using a numerical tool to analyze hydrogeologic systems." *Transcript (Norris) Vol. XXII* at p. 4030.

319. The experts who addressed this issue fall into two classifications. One group consists of experts who regularly apply and use groundwater models but who do not "write code" or make the kind of changes in the computer code that are discussed here. The second group consists of computer modelers who both write and apply models and who do, in fact, "think" in FORTRAN and Perl. Each group has its own perspective. For example, Mr. Hahn is obviously qualified to run models and has a distinguished career in groundwater resource development. He has applied MODFLOW in a variety of circumstances, but Mr. Hahn does not write or modify code. *Transcript (Hahn) Vol. XVIII* at p. 3499. He was reasonably concerned that the "failure to converge" signal appeared in the runs of the groundwater model in this case. At the same time, he testified that he had no opinion what closure criteria were appropriate for the model and could not explain the differences between the solvers available for use with MODFLOW or why one might be preferable for a particular application.

320. Convergence is the process of approaching a head distribution such that every cell is in balance. Put differently, "Convergence is the observation or results of an iterative process that is approaching an answer." *Transcript (Norris) Vol. XXI* at p. 3828, ln. 14-16. Convergence occurs when the groundwater model meets an operator-supplied criteria

for head change within a certain number of iterations[42] by the computer model. *Transcript (Schreüder) Vol. XI* at p. 2009, ln. 1 – 9. The operator-supplied criteria addresses the amount of head change between successive iterations. *Transcript (Schreüder) Vol. XI* at p. 2010, ln. 10 – 13; p. 2015, ln. 8 – p. 2017, ln. 21. If the model satisfies the operator-supplied criteria within the number of iterations allowed (usually 25-30), then the model is said to have "converged." If the model does not reach the operator-supplied criteria within the number of iterations allowed, it gives a "failure to converge" message and ceases to run. *Transcript (Schreüder) Vol. XI* at p. 2016, ln. 22 – p. 2017, ln. 4. Depending upon the type of "solver" being used, the head change criteria may be expressed in units other than units of distance or pressure. When a model does not converge, one would expect to notice that there is not good mass balance. *Transcript (McDonald) Vol. XVIII* at p. 3437. At the same time, the failed-to-converge message in MODFLOW does not necessarily mean that a satisfactory solution to the equation has not been achieved. *Transcript (Larson) Vol. XXV* at p. 4643.

321. A solver is the mathematic procedure used by the groundwater model to solve the groundwater flow equation. The U.S.G.S. has published six solvers for use with MODFLOW 2000, the version of MODFLOW used by the State. Among these solvers are the Strongly Implicit Procedure Package (SIP), the Preconditioned Conjugate-Gradient Package (PCG2), and the Linked-AMG Package (LMG).[43] The State used the LMG solver because it is better at finding the solution when the initial "heads" are not considered to be very close to final "heads." In addition, the LMG solver is faster than the other commonly used solvers, thereby reducing the computer time required to run the steady-state and transient simulations by the model.

322. The closure criterion of the LMG solver is called BCLOSE, a dimensionless value unique to this solver. *Transcript (Schreüder) Vol. XXV* at p. 4719, ln 1-5. In addition to BCLOSE, the LMG solver has a number of settings that can be changed depending upon the problem being solved. Among these are the "ICG switch" and the "DAMP Parameter." In some cases, the LMG solver can perform poorly as a result of a small number of error components that are not eliminated during the algebraic multi-grid cycling by the solver. These error components can prevent convergence, but a few iterations by the ICG (a conjugate gradient solver within the LMG solver), can often reduce these errors and thus assist convergence.

323. The LMG's DAMP parameter can be used to restrict head changes from one iteration to the next. This is useful in nonlinear situations like the groundwater system in the San Luis Valley because it makes the solver's estimates change more slowly from one iteration to the next, thereby avoiding spurious problems created by excessive changes in

[42] Because groundwater flow equations are often nonlinear, that is the change in one variable is not proportional to changes in other variables, the equations are solved by a series of successively refined estimations. This process is referred to as "iterating."

[43] More information on the solvers available for use with MODFLOW 2000 can be found at http://water.usgs.gov/nrp/gwsoftware/modflow2000/mfdoc/solvers.html.

estimates between iterations. An appropriate setting of the DAMP parameter will therefore assist in achieving convergence.

324. There is unquestionably a good deal of professional judgment in the design of a groundwater model. In the operation of the model, there are, likewise, important judgments the modeler must make. The choice of a solver, the utilization of the DAMP parameter and BCLOSE are all areas where the modeler exercises discretion and where the choices made affect the accuracy and even the validity of the model. In this case, the most important area of discretion to discuss is the use of a "mass balance override."

325. Dr. Schreüder's description of the modeling method was dynamic rather than rote. A model must achieve convergence and must have a good overall mass balance. However, he pointed out that a model may achieve both but have such serious anomalies that the solution cannot be right in spite of the fact that the apparent "solution" converged and has good mass balance. The example he used was a solution which converged and had good mass balance but there were large areas of dry cells where one knew from site verification there were not dry cells. *Transcript (Schreüder) Vol. XI* at p. 2032. In a model as large and complex as the RGDSS groundwater model, no one expected the model to converge easily in a few iterations. The testimony of Mr. Norris was especially helpful in reinforcing the notion that during the development of a model, decisions such as what criterion to use for closure, which solver to use, when to revise input to the model rather than change criteria, and when a mass balance is good enough all require professional judgment.

326. In the case of this groundwater model, the modelers had the advantage of ongoing input and consultation with the entire working group that developed the RGDSS. For example, when the model was found to be very sensitive to the accuracy of data regarding the height of streambeds and canal bottoms, Mr. Davey sent people out to survey the stream beds and canal bottoms to improve the input data, and this effort resulted in an immediate improvement in the model performance. Similarly, Mr. Harmon and Dr. Schreüder were in frequent contact over the entire time the RGDSS groundwater model Phase 4 was in development.

327. The Protestors' experts asserted that the RGDSS groundwater model, when run with the LMG solver, did not converge either in the 1990-1998 steady-state version of the model or in the predictive transient version of the model. *Transcript (Norris) Vol. X XI* at p. 3831, ln. 1. Their assertions were principally based upon the "failure to converge" message printed by MODFLOW at various points during the running of these two versions of the model. The Proponents' lead modeler, Dr. Willem Schreüder, disagreed. *Transcript (Schreüder) Vol. XI* at p. 2017, ln. 13 – 24; p. 2031, ln. 10 – p. 2033, ln. 8; see also *Transcript (Larson) Vol. XXV* at p. 4643, ln. 11 – p. 4645, ln. 1. He testified that he set the closure criterion in the LMG solver, "BCLOSE," to such a tight tolerance that he knew the model could not reach this criterion. *Transcript (Schreüder) Vol. XI* at p. 2020, ln. 13 – p. 2021, ln. 2; p. 2285, ln. 6 - 17. He did so because he wanted the model to keep iterating in order to achieve the smallest possible mass balance error. *Transcript (Schreüder) Vol. XI* at p. 2021, ln. 25 – p. 2026, ln. 25. Accordingly, he wrote model code that instructed the groundwater model to ignore the "failure to converge" message and to keep iterating so long as the mass balance error was less than 1%. See *Transcript*

(Schreüder) Vol. XI at p. 2027, ln. 1 – p. 2030, ln. 4. This procedure is called the "mass balance override." By so doing, Dr. Schreüder achieved model results with a mass balance error of one acre-foot out of a total water budget of some 1.6 million acre-feet. *Transcript (Schreüder) Vol. XI* at p. 2019, ln. 22 – 24.

328. The operator-supplied criteria for convergence is related to the groundwater model's mass balance error. MODFLOW assumes that both Darcy's Law and the law of conservation of mass are applicable to the system being modeled. Thus, in MODFLOW the operation of the law of conservation of mass means that the sum of the inflows and outflows are equal to the change in storage. In a perfect world, the result of the model's calculation would show no difference between the sum of inflows and outflows versus the change in storage, but such perfect symmetry should not be expected with groundwater models, as Einstein suggested.

329. In groundwater modeling, the mass balance error is a measure of how well the model has solved the problem posed; in other words, whether the model has calculated at all locations within the model the correct head change which results from the stresses on the model. The experts generally agreed that achieving a small mass balance error is a good indication that the model has found the correct solution to the problem posed. The Protestors' experts asserted, however, that a small mass balance error alone is not sufficient to establish that the model has converged and that a correct solution has been found. They insisted that convergence is a necessary first step.

330. The Proponents' experts replied that the degree of convergence required for a particular model is a judgment by the modelers, which is weighed together with the degree of mass balance error. Dr. Brendecke, a very respected modeler in his own right, had no difficulty concluding that the techniques used by Dr. Schreüder were appropriate, including the use of the mass balance override. He testified that the model converged sufficiently and that the mass balance was accurate. *Transcript (Brendecke) Vol. XIII* at 2473. These experts asserted that in the real world groundwater models often have a few problem cells that may prevent this complete convergence; but if an examination of the model's output shows that these few cells have no material impact on the overall correctness of the solution computed by the model, then the model has indeed found the correct solution to the problem posed. Mr. Steve Larson was a member of the initial modeling team that built MODFLOW. He described circumstances in which he believed it is appropriate and reasonable to override the failure-to-converge check to allow the model to complete the calculation process and he has done so. *Transcript (Larson) Vol. XXV* at pp. 4645-46. State's Exhibit 124, Opinion 2. Mr. Larson reinforced Dr. Schreüder's view that global mass balance is a good indicator of whether the iteration process has produced a satisfactory solution to the system of equations and that this can be so even if one has obtained a "failure to converge" message from MODFLOW. *Transcript (Larson) Vol. XXV* at p. 4650

331. Protestors' Exhibit No. P-1, Appendix H, is an excerpt from the U.S.G.S. publication titled *Guidelines for Evaluating Ground-Water Flow Models* by Thomas E. Reilley and Arlen W. Harbaugh. It states that one guideline to determining whether the groundwater model has reached a proper solution is to determine if the head change criterion is small enough to obtain a solution with minimal error. The head change

criterion is said to have been achieved if the mass balance error over the entire model domain is small, generally less than 0.5%. There is a consensus among the experts that while this guideline is generally followed, they all strive for a smaller mass balance error.[44] Put in terms of depth, groundwater modelers often use 1/100th of a foot, one-eighth of an inch, as the closure criterion.

332. There was no dispute that the 1990-1998 steady-state groundwater model printed out "failure to converge" messages. It was also undisputed that when the State re-ran the 1990-1998 steady-state model with less stringent closure criteria than originally used, and also ran it using the PCG Solver, that it met the standards for convergence described in Protestors' Exhibit No. P-1, App. H, without MODFLOW printing a "failure to converge" message. *Transcript (Schreüder) Vol. XXV* at p. 4730, ln. 22 – 25. In this process the mass balance error in the model was still extremely small, on the order of 5 acre-feet. *Transcript (Schreüder) Vol. XXV* at p. 4737, ln. 1 – 7. Thus, despite the controversy engendered by the State's initial use of a very small closure criterion to minimize mass balance errors, and its decision to override the "failure to converge" message printed by MODFLOW in this process, the 1990-1998 steady-state groundwater model did, in fact, converge. See also *Transcript (Schreüder) Vol. XXV* at p.4737, ln. 8 – 4733, ln. 20.

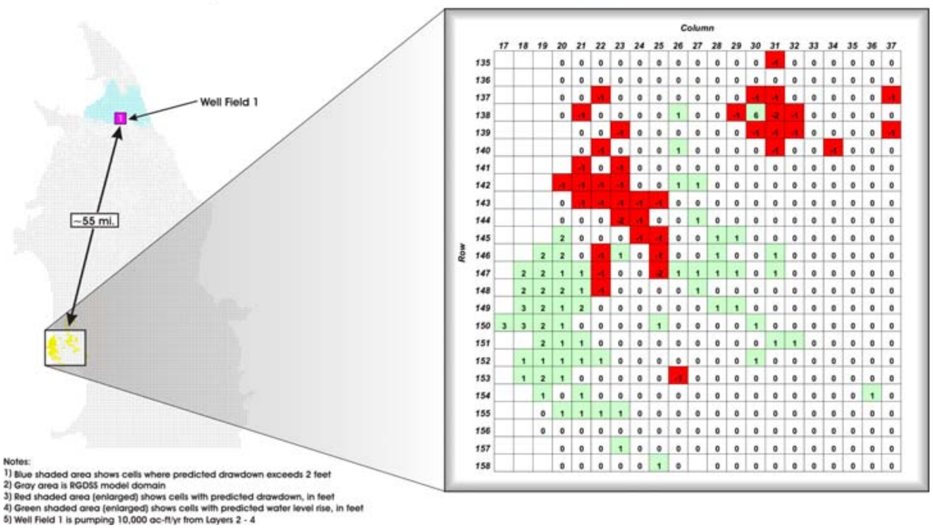
333. The Protestors objected to the admission of the results of the State's rebuttal runs of the 1990-1998 steady-state model employing different solver parameters and using a different solver. The Protestors agreed, however, that use of a different solver did not change the model. They did contend, however, that the State's use of MODFLOW 2000 version 1.15.01 constituted a "new model," as contrasted to MODFLOW 2000 version 1.10, which was not properly disclosed. The Court does not agree and finds that MODFLOW version 1.15.01 was an update issued by the U.S.G.S. to fix small problems in the prior release of the MODFLOW model program and that none of those changes affected the fundamental structure or operation of the MODFLOW model program. The specific fixes addressed in this update are fully documented at the U.S.G.S. website previously cited. The State used the same input files as used in its prior operation of the model and did not use any of the new "packages" made available for MODFLOW version 1.15.01. Thus, the State's rebuttal runs of the 1990-1998 steady-state groundwater model did not constitute a new or different groundwater model than that previously disclosed and timely made available to the Protestors. See *Transcript (Schreüder) Vol. XXV* at p. 4726, ln. 11 – p. 5729, ln. 22.

334. The Protestors' experts also claimed that the 1990-1998 steady-state model is fundamentally unreliable because its calculations do not represent reasonable, valid, or even physically-possible results. Protestors' Exhibit No. P-1, *Professional Opinion No. 3,* pp. 11-15. The Protestors' experts used the RGDSS 1990-1998 steady-state groundwater model, as published by the State, to perform a series of tests consisting of small changes in pumping stress and then observing the model's results. They did contend that the results show anomalous, unreasonable, and physically impossible results, all of which demonstrate a flawed model. Protestors' Exhibit P-1, Figure 13, reproduced below is one of their examples. The steady-state model run by Mr. Hahn and Mr. Norris

[44] In the RGDSS groundwater model, a mass balance error of 0.5% represents 8,000 acre-feet annually.

shows a well in the north end of the Valley causing significant impact to cells in the Capulin area, over 50 miles away. This is clearly not consistent with physical reality.

Figure 14 - UNEXPECTED WATER LEVEL CHANGES IN LAYER 1 DUE TO PUMPING WELLFIELD 1



335. The Proponents' experts responded by pointing out that the 1990-1998 steady-state model was not intended or used by the State for predictive purposes, but was rather used solely as a stepping stone to the transient groundwater model. The significance of this distinction is that the LMG solver, as used by the State in the steady-state model, was not set to make the type of refined calculations needed when using a steady-state model for predictive purposes. State's Exhibit No. 125, *Rebuttal Report of Dr. Willem Schreüder*; *Transcript (Schreüder) Vol. XXV* at p. 4717, ln. 4 – p. 4718, ln. 1; p. 4718, ln. 15 – 24; *Vol. XXV* at p. 4742 ln. 7-22. The State's experts performed analyses to demonstrate that these claims by the Protestors' experts were in error. First, they ran the steady-state model using the PCG solver and with new stresses similar to those used by the Protestors' experts. The results of those runs show none of the anomalous, unreasonable, or physically impossible results encountered by the Protestors' experts when running the model using the unmodified LMG solver. *Testimony (Schreüder) Vol. XXV* at p. 4747, ln. 15-18 – p. 4748, ln. 4; p. 4747, ln. 12 – 15. Second, the Proponents' experts ran the steady-state model using the LMG solver with the ICG switch "on" and the DAMP parameter set to reduce the variation in estimates between iterations. *Testimony (Schreüder) Vol. XXV* at p. 4732, ln. 11 – 21. Again, the results of these runs of the model do not show the anomalous, unreasonable or physically impossible results encountered by the Protestors' experts. *Testimony (Schreüder) Vol. XXV* at p. 4742, ln 15 – 22; p. 4745, ln. 13 – p. 4746, ln. 17. The discussion of these runs by the respective sets of experts led the Court to conclude that the Protestors' experts are significantly less familiar than Dr. Schreüder with the ways in which the various solvers work in MODFLOW and the consequences of the choices made in choosing a solver. Equally important, various experts agreed that it was not unexpected that there would be some

problems with the model along the edge of the domain. The Capulin area where the anomalous result appears in Protestors' Exhibit P-1, Figure 13 is along the edge of the model domain. Dr. Brendecke separately built a model of the Conejos River and has intimate knowledge of the problems he encountered where the Conejos River entered the Valley. He described calibration along the rim as "knotty." *Testimony (Brendecke) Vol. XIII* at p. 2380.

336. RG-26 illustrates Dr. Schreüder's view that when properly configured, the steady-state model is convergent.

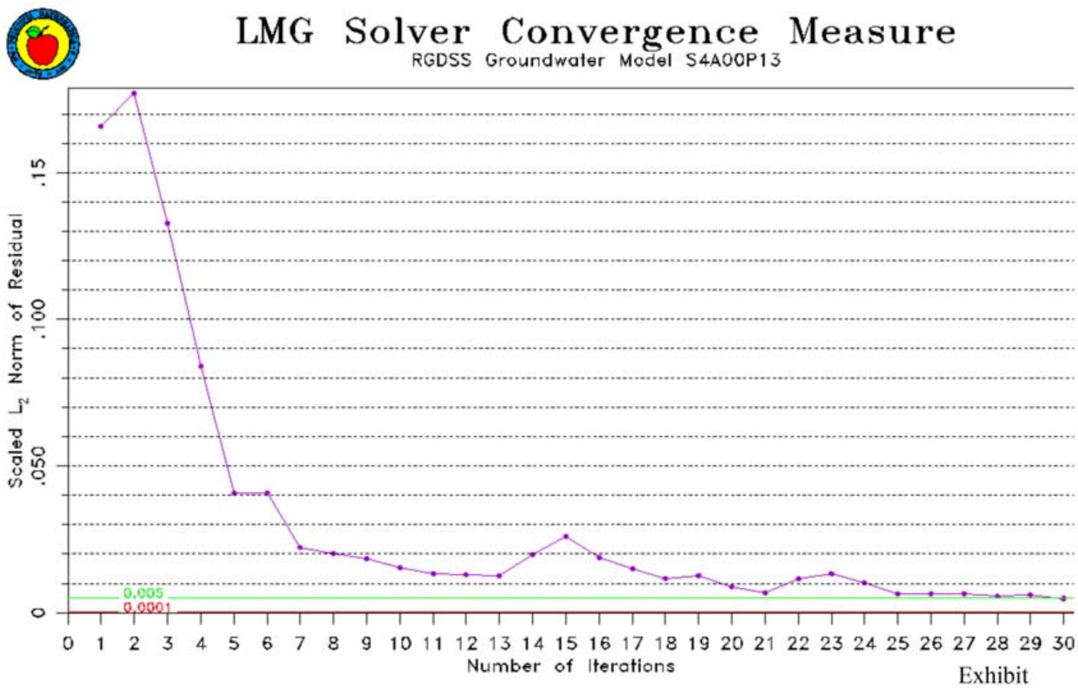


Exhibit RG-26

337. Based upon the evidence, the Court finds that the anomalous, unreasonable, and physically impossible results reported by the Protestors' experts are the result of the settings employed for the LMG solver and are not indicative of fundamental flaws in the RGDSS steady-state groundwater model. When the LMG solver parameters are set appropriately for a steady-state groundwater model that is to be used for predictive purposes, the problems do not appear. Since the State was not using the steady-state model for predictive purposes, it had no reason to set the LMG solver parameters in this manner until presented with the Protestors' predictive runs. *Testimony (Schreüder) Vol. XXV* at p. 4752, p. 15 – p. 4753, ln. 8.

338. The Protestors' experts also argued that the predictive transient groundwater model does not converge. The Proponents' experts agreed that during certain time steps during the runs of the transient groundwater model that MODFLOW printed a "failure to converge" message and that this message was "overridden" so long as the global mass balance error was less than 1%. The Proponents' experts overrode the "failure to converge" message because they wanted the run to complete so they could evaluate any problems in the context of the overall solution reached by the model.

339. The Protestors' experts' assertions that the transient model failed to converge was based upon the "failure to converge" message printed out at the end of various time steps in the transient model runs. See Protestors' Exhibits No. P-71a, b and c; P-72a and b. Each time when MODFLOW printed a "failure to converge" message the mass balance override instructed the model to keep iterating. The Protestors asserted that the recurrence of this "failure to converge" message is the result of fundamental flaws in the RGDSS groundwater model that must be corrected before the model can be considered reliable for any predictive purposes. They further asserted that these problems must first be corrected in the steady-state model before any further transient simulations are attempted.

340. The Proponents' experts demonstrated that the "failure to converge" messages printed in the transient model run were due to "problems" in 18 cells out of 51,015 active cells in the model domain. The Proponents also established that 3 of these 18 cells were the cause of the "failure to converge" message the majority of the time. And the Proponents established that most of these "problem" cells had very small groundwater level changes and were located in either the southwestern edge of the model domain in an area where the depth to groundwater is over 100 feet and where the aquifer in question is perched and very thinly saturated. One cell that repeatedly failed to meet the closure criteria was located in the San Luis Hills, had 120 acre-feet of annual pumping, and had virtually no effect on the results of the model. See State's Exhibit 125; *Testimony (Schreüder) Vol. XXV* at p. 4759, ln. 15 – p. 4761, ln. 15. Likewise, the non-converging cells in the southwest edge of the model domain had so little water in them that their elimination from the model domain had essentially no effect in the results of the transient groundwater model. See State's Exhibit No. 125; *Transcript (Schreüder) Vol. XXV* at p. 4761, ln. 16 – 4764, ln. 20.

341. After hearing the testimony of the parties' expert witnesses, including the testimony of Mr. McDonald and Mr. Larson, the Court finds that while complete convergence of a groundwater model is desirable, in the circumstances of this case, this technical convergence of each cell in each time step alone is not the sole or even, necessarily, the proper measure of whether the RGDSS groundwater model has found the proper solution to the problem posed. The evidence demonstrates that in a basin-scale model of the size and complexity of the RGDSS groundwater model, it is not unusual to have a few small areas where the model has difficulty reaching a "converged" solution for every single grid cell. The Court finds convincing the testimony of Mr. Larson that with a model of this scale it is very likely that the model has found the correct solution to the problem posed when it has a very small mass balance error even though it has not achieved convergence in every single model cell. *Transcript (Larson) Vol. XXV* at p. 4650, ln. 1 – p. 4651, ln. 17; p. 4667, ln. 10 – p. 4668, ln. 11. In such situations the

modeler must look at the cells or areas where the model did not achieve convergence and decide if those cells or areas are important to the problem posed for the model. If those areas are small and not significant to the problem the model is asked to solve, then the model is useful and reliable, notwithstanding the failure to achieve technical convergence. The transient runs of the RGDSS groundwater model had a very small mass balance error, and the cells that did not meet the operator-selected convergence criteria were few and located in areas that had no material impact on the overall solution reached by the model. Accordingly, the Court finds that the failure of the RGDSS groundwater model to achieve complete convergence in every cell in the model domain during every time step, does not mean the model is fundamentally flawed or that it cannot be reliably used for the purposes contemplated by the Rules.

342. The Court also concludes that the use of the mass balance override is an acceptable professional judgment when exercised by a skilled modeler such as Dr. Schreüder. The testimony is clear that not every modeler is comfortable with this override technique. It is equally clear that many users of models would not have the knowledge to utilize such a tool. The evidence shows that while Dr. Schreüder has refined this method, other modelers have "commented out" the failure-to-converge flag in order to help the solver make its determination of whether to continue. Dr. Schreüder's technique is not, therefore, a radical departure from one common way in which some modelers address issues of convergence in large scale models. Dr. Brendecke found no issue with this methodology nor did Mr. Slattery or the other members of the peer review team on the RGDSS groundwater model.

343. This same approach to complex basin-scale modeling and the use of a mass balance override to permit MODFLOW to continue calculating has been used and sanctioned in the interstate litigation involving Kansas, Nebraska and Colorado over the Republican River Compact, United States Supreme Court, Original No. 128. See section 37-67-101, C.R.S. (2005) (Republican River Compact). In that case, the three states entered into a settlement based, in large part, upon a groundwater computer model that would be used for accounting and computation of stream flow depletions from groundwater pumping and stream flow accretions from water imported into the basin. See *Final Report of the Special Master with Certificate of Adoption of the RRCA Groundwater Model*, available at http://www.republicanrivercompact.org. That groundwater model uses the MODFLOW model program and invokes a mass balance override that functions in essentially the same manner as the mass balance override in the RGDSS groundwater model. See Exhibit No. RG-1; *Transcript (Schreüder) Vol. XI* at p. 2030, ln. 12 – p. 2031, ln. 9. The RRCA groundwater model was approved by each of the three states as the basis for the settlement of that litigation. Mr. McDonald was the lead modeler for Nebraska in that proceeding. Mr. Larson was the lead modeler for Kansas, and Dr. Schreüder was the lead modeler for Colorado and was tasked with the final model design submitted to the master and the U. S. Supreme Court.

344. Protestors pointed out that the use of the mass balance override code written by Dr. Schreüder has not been discussed in any peer publication. While this code has not been accepted as of yet by the U.S.G.S., nor received endorsement in a scientific publication, it has been subjected to peer review in the Republican River case and in this case. While Mr. McDonald, who is an author of MODFLOW and certainly an expert of

the highest qualifications, was critical of its use, he was himself a member of the technical advisory committee on the Republican River representing the State of Nebraska; and in that capacity he endorsed the groundwater model which used the same technique. The Court was surprised to hear him testify that he did not know such a technique was used since his review of the documentation of the model would have included printouts reflecting the failure-to-converge flags and the effect of the mass balance override in allowing the run to continue. As he noted, as lead modeler for Nebraska, his role was "the expert on groundwater model….I also had to ensure that I believed in it (the groundwater model) and that I could say to the attorney general that, on the whole, I thought that model was safe for him to rely upon in evaluating the depletions to streams caused by pumping." Mr. McDonald testified that when contacted in regard to this case, he contacted members of his modeling team in Nebraska regarding the mass balance override technique. They readily acknowledged that they knew the mass balance override was used and, obviously, had not seen that as a problem or a deviation from acceptable modeling techniques. *Transcript (McDonald) Vol. XVIII* at p. 3441.

345. Additionally, Mr. McDonald's modeling team in the Republican River case constructed a shadow model of the Schreüder model adopted and ran its own comparative runs. Mr. McDonald's testimony underscored the fact that a mathematical model should not be expected to be perfect and that a technical advisory group as highly qualified as the one in the Republican River Compact would expect to have some differences. As Mr. McDonald testified:

> Well, actually I concluded that our Shadow model was similar enough to the Willem (Schreüder) model. And I thought the Shadow model was going to be about as good as we would get; that is, we were supposed to arrive at consensus on this project. So obviously, each party conceded some points on some places and didn't concede on others. So we were not looking for a perfect model. We were looking for a model we could live with.

Transcript (McDonald) Vol. XVIII at p. 3444. The same can be said of the RGDSS groundwater model. It is far from perfect. But it is the best model it can be at this point in time, and the State and water users and Water Court will find it useful for the purposes for which it is designed.

346. Importantly, the Republican River groundwater model has been in operation for some time without complaint directed at this issue. The documentation for both the Republican River groundwater model and the RGDSS groundwater model have been available online for some time. The fact that the mass balance override methodology has not been the subject of critical professional comment reinforces the opinions of Dr. Schreüder, Dr. Brendecke, Mr. Slattery, and Mr. Larson that this is an accepted method, well within professional standards for utilization of MODFLOW. While the Court heard the criticisms and concerns about its use, those criticisms are not well-founded in the context of a large basin model such as the RGDSS groundwater model.

347. Finally, the testimony of Mr. Larson emphasized that other researchers, including Mr. Larson, have overridden the convergence criteria to allow MODFLOW to continue in

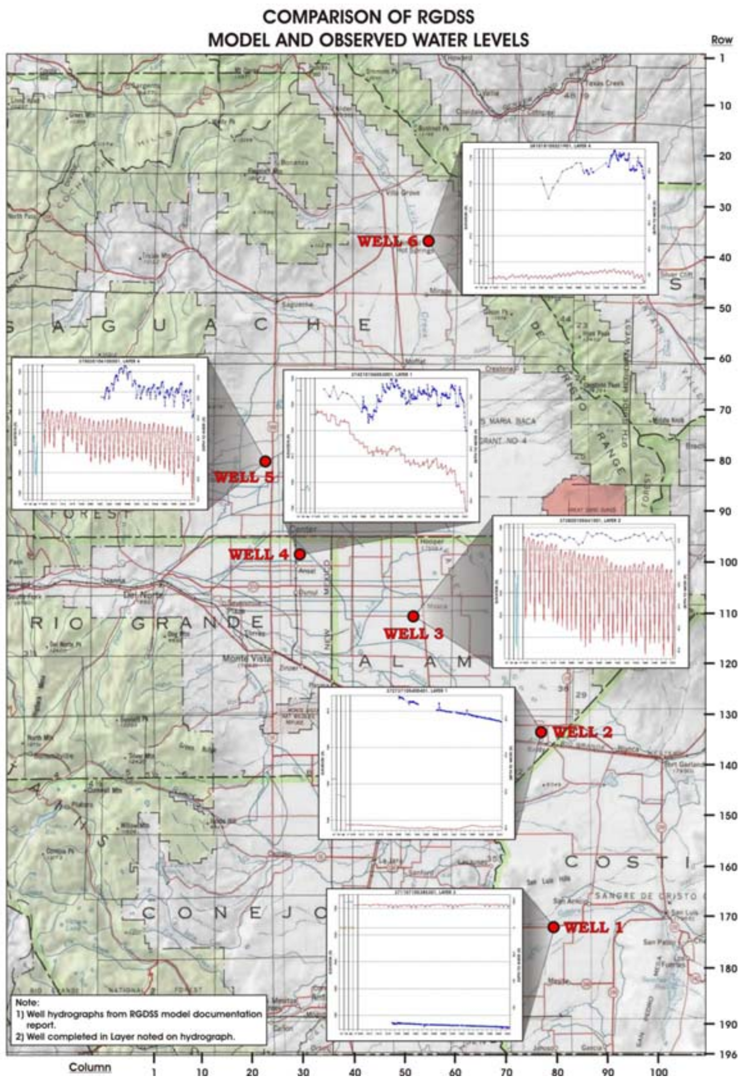
order to overcome instabilities, and that some of the recent MODFLOW application explicitly overrides the convergence criteria in a way similar to what Dr. Schreüder has done. PEST is a program which works with MODFLOW, and has a specific option included to override the convergence criteria. *Transcript (Larson) Vol. XXV* at p. 4654-55. The Court concludes that the mass balance override technique employed by Dr. Schreüder is reasonable and appropriate and is accepted by a substantial number of his fellow modelers. In terms of this model and the equations or questions it was asked to solve, the Court finds the weight of the evidence supports the conclusion that the model is satisfactorily, albeit imperfectly, convergent and that it has good mass balance.

B. Calibration

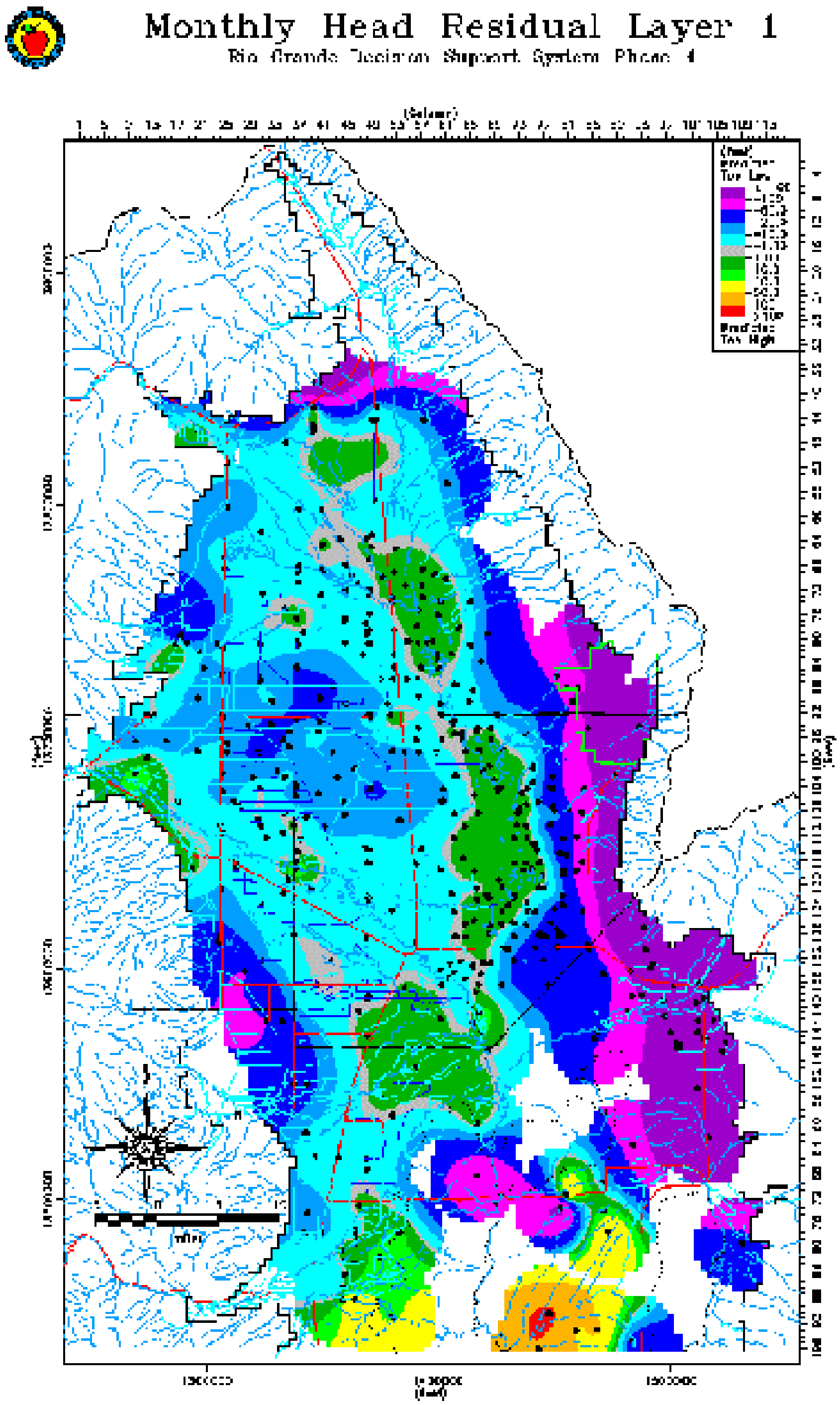
348. Calibration is the process of refining a groundwater model representation of the hydrogeologic framework to achieve a desired degree of correspondence between the model simulation and field observation.[45] It involves trial-and-error adjustments of the groundwater model to achieve the closest achievable correspondence between the model simulation and observed data. A description of how this works is found in the testimony of Dr. Schreüder at Vol. X, pp. 1929-32. During calibration, the difference between the observed values and the simulated value of a variable such as head is measured, and the difference is called a residual. In a "perfect" simulation, the residual would be zero. There is certainly a degree of professional judgment as to what degree of calibration is necessary for a particular groundwater model, and the standard for accuracy for a regional model such as the RGDSS groundwater model is not and should not be expected to be the same as for 300-acre model addressing contamination of groundwater, *Transcript (Slattery) Vol. X* at pp. 1500-02.

349. The Protestors asserted that the RGDSS groundwater model is not properly calibrated. In support of this claim they pointed out areas in the model domain where the predictions of the model vary fairly substantially from measured groundwater levels. See e.g. Protesters' Exhibits No. P-7 and P-36 (displayed below). P-36 displays a comparison of some of the observed well heads and the predicted heads which were discussed at length during the trial.

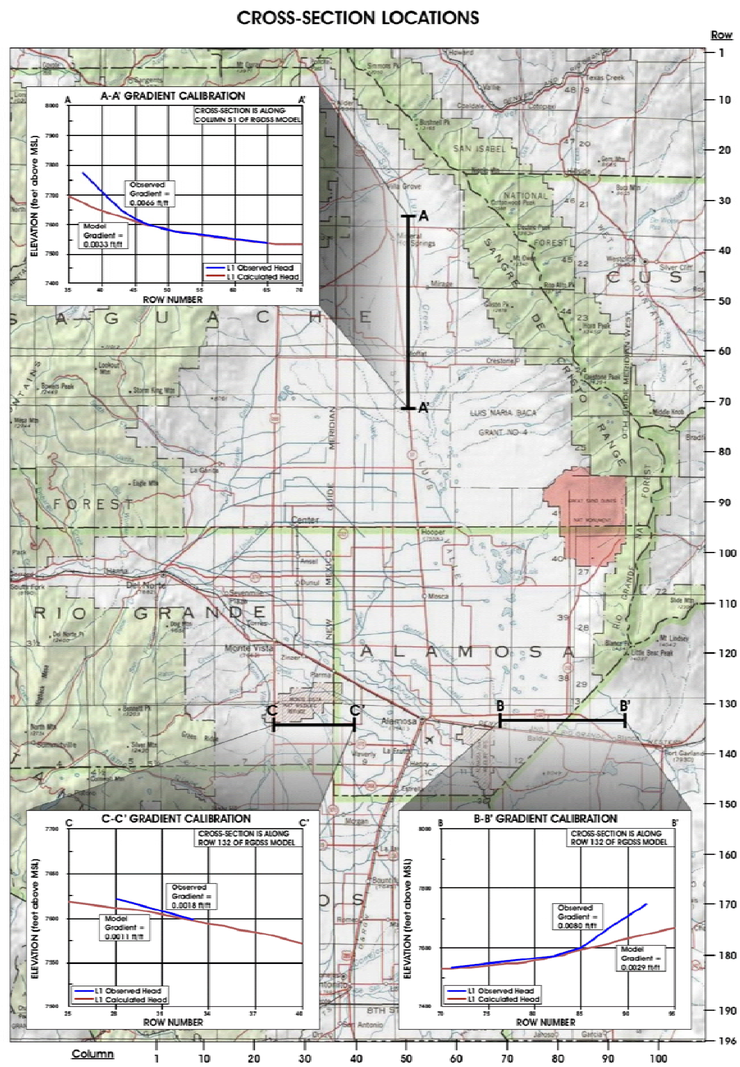
[45] ASTM Guide D-5981.



350. Head residuals in the calibration process affect the ability of the model to accurately determine the impact associated with future withdrawals in the confined aquifer. *Transcript (Schreüder) Vol. XI* at pp. 2183-4. The head residuals were depicted in a variety of exhibits using both the steady-state and monthly versions of the RGDSS groundwater model. An example is P-22 which depicts the head residuals in Layer 1, based on M4A00P13. The model extrapolated predicted head residuals for areas where there are known heads. It is fair to say that these maps, like the specific hydrographs selected from the calibration process and prominently used for cross-examination of Dr. Schreüder, illustrate that the model is imperfect and in some areas of the domain such as the Costilla Plain and the area between La Sauses and the San Luis Hills, the model's predictions are not reliable for reasons not understood at this time by the modelers or the State. It is equally evident that along the edge of the domain the model is also operating in a less reliable manner. This is evident in the monthly head residuals for Layer 1 below and also on assorted hydrographs selected for discussion by Mr. Norris and Mr. Hahn, as well as in the cross-examination of Dr. Schreüder.


Monthly Head Residual Layer 1
Rio Grande Decision Support System Phase 4

351. The Protestors also asserted that the groundwater model has a bias toward under-predicting rather than over-predicting groundwater levels, see e.g. Protestors' Exhibit No. P-41, and that the groundwater gradients in the model does not accurately replicate the observed groundwater gradients. See e.g. Protestors' Exhibits No. P-42 and P-43. Based upon these observations, the Protesters asserted that the RGDSS groundwater model's predictions cannot be accurate or reliable because the model does not correctly reflect the flow of groundwater and does not correctly reflect groundwater elevations, both of which they asserted are central to correct predictions of ET_g, stream gains and losses, and the impacts of new withdrawals of groundwater from the confined aquifer. Protestors' Exhibit P-42 illustrates the concerns expressed by Mr. Norris.



352. The Proponents' experts responded to these criticisms in several ways. First, they unapologetically asserted that the RGDSS groundwater model has achieved a good level of calibration for a basin-scale groundwater model. They asserted that in a basin-scale groundwater model, a predicted water level that is within 5 to 10 feet of an observed water level in an unconfined aquifer is a good match; that predicted water levels in an unconfined aquifer that are between 10 to 20 feet of an observed water level are a fair match, and that any greater disparity is not so good. With respect to a confined aquifer, the Proponents' experts asserted that because a small change in storage can translate into a large change in artesian pressure, it is much more difficult to accurately predict changes in artesian pressure. For this reason, they asserted that if a predicted artesian water level is within 20 feet of the observed water level, the match is good. If the predicted artesian water level is within 40 feet of the observed water level, the match is fair; and any greater disparity is not so good. *Transcript (Slattery) Vol. VIII* at p. 1590, ln 22 – p. 1594, ln. 2; *Transcript (Schreüder) Vol. XI* at p. 1976, ln. 2 – 6; p. 1977, ln. 11 – p. 1978, ln. 3.

353. Using these standards the Proponents' experts did contend that the RGDSS groundwater model has a good calibration for a basin-scale model covering 3,100 square miles, particularly given the lack of available historical groundwater level data in some areas and in some layers of the model. They pointed out that 41% of the predicted unconfined aquifer water levels are within 5 feet of the observed levels, and 19% of these predictions are within 10 feet of the observed levels, for a total of 60% falling into their "good" category. Another 13% fall into the "fair" category of within 10 to 20 feet of observed. See Exhibit No. RG-30; *Transcript (Schreüder) Vol. XI* at p. 1976, ln. 7 – p. 1977, ln. 4. With respect to the confined aquifer, the Proponents' experts showed that 59% of the wells fall into the "good" category and that 29% fall into the "fair" category, with the remaining 12% being not so good. See Exhibit No. RG-31; *Transcript (Schreüder) Vol. XI* at p. 1979, ln. 24 – 25 ; p. 1980, ln. 23. Dr. Schreüder responded to cross-examination which underscored the fact that this range of calibration would not be acceptable for a smaller scale model covering a few acres or square miles, by testifying:

> It's simply that when you deal with basin-scale models, the complexities that you encounter in both the types of geologic complexities that occur, the types of uncertainties that you have that's associated with the specific measurements, and all of those factors combine to simply make it a fact of life that, in basin-scale models, the level of calibration that you can expect are as Mr. Slattery and I have described.

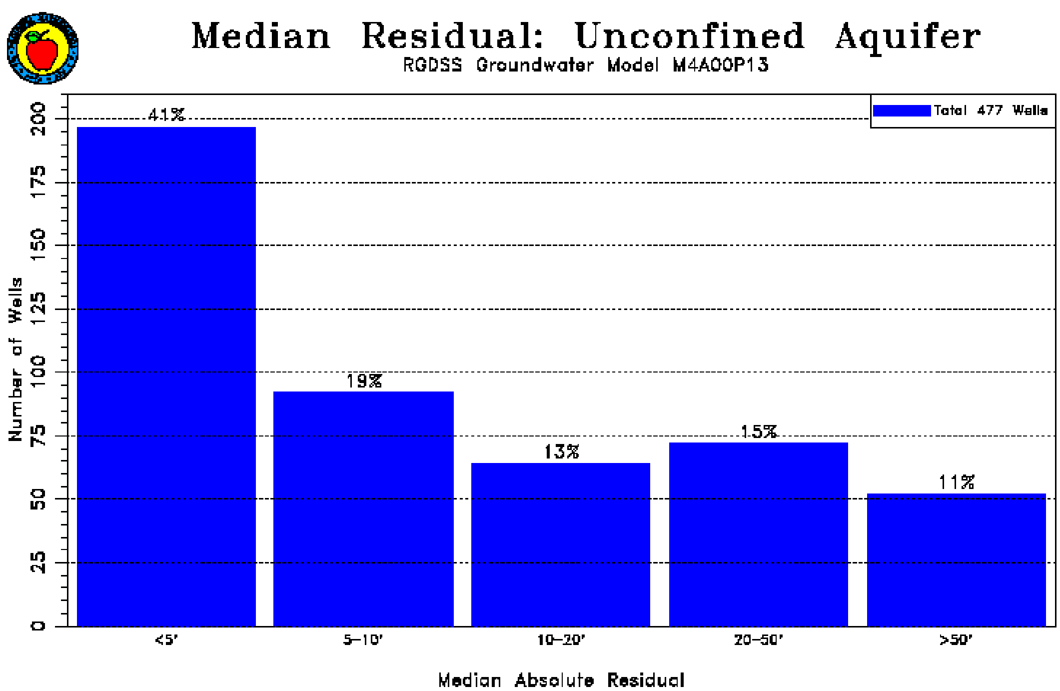
Transcript (Schreüder) Vol. XI at p. 2188. Mr. Norris and Mr. Hahn both acknowledged the complexity of this model. Mr. Norris said:

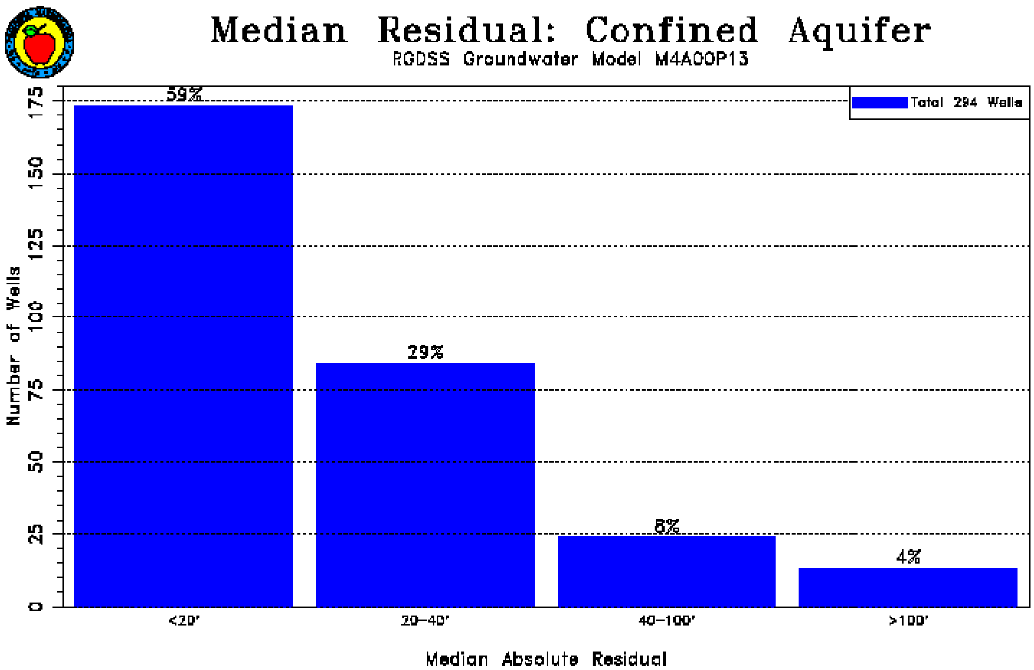
> For a basin-scale model, I think the RGDSS groundwater model attempts to deal with and look at a far more complicated set of stresses--or break the stresses into a far more complicated set of--subset than any basin-scale model I have dealt with. *Transcript (Norris) Vol. XXII* at p. 4027.

354. The Proponents' experts acknowledged that the RGDSS groundwater model is not without problems. They acknowledged that there are areas in the Valley where the operation of the physical system is not yet well understood; and in those areas, such as

the Costilla Plain, the groundwater model's predictions are not as accurate as the State desires them to be. See e.g. *Transcript (Schreüder) Vol. XI* at p. 1978, ln. 12 – p. 1979, ln. 23; *Vol. XII* at p. 2287, ln. 25 – p. 2292, ln. 17. Likewise, they acknowledged that near the confluence of the Rio Grande and Conejos the model has problems with excessive groundwater inflows, and a similar problem occurs where the Rio San Antonio enters the model domain. *Transcript (Schreüder) Vol. XII* at p. 2297, ln. 16 – p. 2229, ln. 22.

355. What constitutes "good" calibration is obviously disputed. The monthly transient simulation of head residuals in the unconfined aquifer and confined aquifer by the monthly transient version of P13 (M4A00P13) was presented as Exhibits RG-30 and RG-31. RG- 30 shows that 26% of the wells are more than 20 feet off of the actual head. These are "not as good" or "not as reliable" in Mr. Slattery's vocabulary. Understanding that there are 477 wells with real-world data to compare to, this exhibit is a good illustration of the state of the model at present. Similarly, RG-31 gives a picture of the groundwater model's level of accuracy at present for the confined aquifer.





356. The State is engaged in continuing work to improve the groundwater model and to resolve the problems it has encountered. The proposed Rules contemplate the ongoing improvement of the RGDSS groundwater model and that the State Engineer will use the improved versions of the RGDSS groundwater model as it evolves over time. Events such as the adoption of Rules[46] Governing the Measurement of Ground Water Diversions which took place August 1, 2006, and which provide for mandatory measurement of withdrawals from the confined and unconfined aquifers by totalizing flow meters, ensure that the database of inputs in the RGDSS will improve and effect certain improvements in the ability of the groundwater model to make more accurate predictions.

357. The Proponents' experts did not resort to artificial adjustment of model parameters to improve the model's predicted groundwater levels. Rather, the Proponents' experts felt it was better not to resort to solutions that, while eliminating the problem, could not be supported by the available data. Therefore, Proponents' experts chose to leave these problem areas in the model as an accurate representation of the current state of their understanding of the groundwater systems in the Valley. See e.g. *Transcript (Slattery) Vol. VIII* at p. 1509, ln. 3 – 9. The State, frankly, acknowledged the problems in the groundwater model that had not been resolved by June 30, 2004.

[46] Order Approving Rules Governing the Measurement of Ground Water Diversions Located in Water Division No. 3, Rio Grande Basin, dated August 1, 2006, in 2005 CW 12.

358. Despite the existence of problem areas in the model, the Proponents' experts testified that the model has achieved a good state of calibration. See e.g. *Transcript (Schreüder) Vol. XI* at p. 1972, ln. 10 – 21; *Transcript (Brendecke) Vol. XIII* at p. 2395, ln. 25 – p. 2396, ln. 22. In support of their opinions they pointed out that the model is not calibrated solely to groundwater and artesian pressure levels, but that it is also calibrated to ET_g by phreatophytes and to stream gains and losses or "fluxes." State's Exhibit 1 at Ch. 5, p. 1; *Transcript (Schreüder) Vol. XI* at p. 1959, ln. 15 – 22; p. 1963, ln. 2 – 7; p. 1967, ln. 18 – p. 1968, ln. 2; *Vol. XII* at p. 2315, ln. 10 - 16.

359. The calibration to ET_g was accomplished by comparing the amount and areal distribution of ET_g by phreatophytes predicted by the model to an independent estimate of ET_g by phreatophytes developed by Dr. David Cooper, *et al.*, based upon the distribution of phreatophytic plant communities and their relative vigor as determined from their leaf area index. *Transcript (Schreüder) Vol. XI* at p. 1968, ln. 3 – 16. The results of this effort show a good correlation between the distribution and magnitude of ET_g predicted by the RGDSS groundwater model as compared to the distribution and magnitude of the independent ET_g estimate. *Transcript (Schreüder) Vol. XI* at p. 1968, ln. 17 – p. 1970, ln. 5; *Vol. XXV* at p. 4767, ln. 10 – p. 4768, ln. 23. From this the Proponents' experts concluded that the groundwater model's predicted groundwater levels in the large areas of the model domain where the phreatophytes are located cannot be too far off or the model's prediction of ET_g would not correlate with the independent prediction.

360. Likewise, the Proponents' experts testified that the RGDSS groundwater model's predictions do a good job of matching observed stream gains from the aquifer and losses to the aquifer. See e.g. *Transcript (Schreüder) Vol. XI* at p. 1962, ln. 2 – p. 1965, ln. 20; *Vol. XXV* at p. 4765, ln. 3 – p. 4766, ln. 3. They testified that if the gradients, flow paths, and level of groundwater in the RGDSS groundwater model had substantial problems, the model would be unable to predict stream gains and losses as well as it does. *Transcript (Schreüder) Vol. XI* at p. 1965, ln. 21 – p. 1966, ln. 14; *Vol. XXV* at p. 4766, ln. 4 – 9. Dr. Schreüder also observed the fact that the residual heads are off more than one would like, does not equate to inaccuracy in predicting changes to the system which is what one would be most anxious to evaluate with a proposed new withdrawal. *Transcript (Schreüder) Vol. XI* at pp. 2195-96. Under persistent challenge to the documentation of calibration[47] Dr. Schreüder specifically reviewed the various tables contained in the exhibit and demonstrated the overall reliability of the groundwater model. The documentation of the calibration, taken as a whole, shows the model is, as Dr. Schreüder said, "pretty darn good" in simulating stream flows. In fact, as a global model of the Basin, counsel for Protestors seemed to agree with that assessment.[48] A proper verification of the model was also performed, and this is reflected in the "no pumping" simulation which is identified formally as N4A00P13, and which can be seen on the RGDSS Groundwater Model Water Budget. Exhibit RG-25.

[47] See generally, State Exhibit, Model Documentation, 05 Calibration.

[48] "You know, I agree with you on the global scale," Mr. Bushong, *Transcript (Schreüder) Vol. XI* at p. 2217.

361. Based upon the totality of evidence, the Court finds that the RGDSS groundwater model has achieved a reasonable degree of calibration for a basin-scale model, particularly given the complexities that this groundwater model must address. See for example, *Transcript (Brendecke) Vol. XIII* at 2396. It is specifically useful for the promulgation and evaluation of the confined aquifer Rules proposed in this case and for evaluating the fundamental question of sustainability of the aquifer. See *Transcript (Brendecke) Vol. XIII* at 2397.

362. The Protestors' experts Mr. Hahn and Mr. Norris both agreed that the RGDSS is a very complex model and one that attempts to deal with a complicated set of stresses. The Court further finds that this degree of calibration is sufficient for the purpose for which the model is to be used under the Rules. The Court reiterates, however, that there are areas in the Valley, in particular the Costilla Plain, where the model does not perform as well as it does in other areas of the Valley and where it would be a "great idea" to improve the model. *Transcript (Schreüder) Vol. XI* at p. 2192. Thus, the State Engineer must use particular care in the application and interpretation of the model's results in that area and in the other areas of the Valley where the groundwater model still has unresolved problems. And in the application of the model under the Rules, the State Engineer should consider all reliable new and site-specific information an applicant can offer to assist in the evaluation of a particular application. Likewise, the Court understands that the State Engineer intends to continue his work to improve the groundwater model and address the remaining unresolved problems. The Court expects and intends that the State Engineer will to do so before applying the groundwater model to other uses. The Court concludes that even with the obvious imperfections that exist in RGDSS groundwater model P13, it is calibrated to a reasonable degree and that it is appropriate to use it in the manner contemplated by the proposed Rules. Dr. Schreüder was cross-examined at length about the predictive use of the model and his response was informative. He suggested that for an area such as the Costilla Plain, the model can still be used but that the predictions would be "less reliable" and therefore:

> …it would behoove us, in such an instance, to go and study that particular area, that very localized area, in much more detail and probably make some refinements to the model before you use the model to explicitly model such an instance.

Transcript (Schreüder) Vol. XI at p. 2191.

363. The State Engineer and the Water Court both understand that the RGDSS groundwater model is a point of beginning; a presumptive starting point for evaluation of any proposed new withdrawal. It is nothing more and nothing less.

C. Sensitivity Analyses Were Performed Throughout the Development of the RGDSS Groundwater Model

364. The Protestors asserted that the Court cannot accept or approve the State Engineer's use of the RGDSS groundwater model because the State has not completed and documented a formal sensitivity analysis of the model. As described above, a

sensitivity analysis is the adjustment of model input parameters, running the model, and observing the changes in the model's output as a result of the change input parameters. See generally *Transcript (Bennett) Vol. XIV* at p. 2601, ln. 7 – 25; p. 2602, ln.1 - 5. The purpose of this analysis is to understand the relative effect of input parameters on the model's output. The most sensitive parameters are those that are most important for causing the model to match observed values.

365. The evidence establishes that the State Engineer conducted and documented "formal" sensitivity analyses on the Phase 1 and Phase 2 RGDSS groundwater model. *Transcript (Bennett) Vol. XIV* at p. 2602, ln. 6 – 14; p. 2612, ln. p. 10 – 21; *Vol. XV* at p. 2804, ln. 17 - 23. The documentation for the Phase 3 RGDSS groundwater model was inadvertently included in State's Exhibit No. 1, Appendix M, the documentation for the Phase 4 RGDSS groundwater model. *Transcript (Bennett) Vol. XIV* at p. 2592, ln. 3 – 16.

366. The formal documentation of the sensitivity analyses on the Phase 4 groundwater model (P13) had been completed by the State before trial, and it had prepared at least one draft of that documentation. See State's Exhibit No. 56, *Draft RGDSS Ground Water Phase 4 Task 56 Ground Water Model Sensitivity Analysis.* The statutory deadline for filing the proposed Rules created an artificial timeline which affected not only the documentation of the formal sensitivity analysis but other aspects of the development of the groundwater model.

367. The purpose of a sensitivity analysis is to enable the modelers to better understand the model and to provide them the opportunity to collect additional data or further examine existing data relevant to sensitive model parameters so that the model can be more accurate in its predictions or problem solving. The purpose of formally documenting a sensitivity analysis is to provide those not familiar with the model a means to understand the model and its sensitivities. Thus, while formal documentation of a model's sensitivities is a good practice, the absence of the completed documentation does not mean that adequate sensitivity analyses have not been performed on the model. See *Transcript (Schreüder) Vol. XI* at p. 2007, ln. 17 – p. 2008, ln. 17.

368. Sensitivity analyses are part of standard groundwater monitoring protocols. See e.g. Exhibit No. RG-4. Sensitivity analyses are also inherently part of model calibration. The evidence in this case establishes that much of the work of the peer review committee for the Phase 4 RGDSS groundwater model consisted of conducting sensitivity analyses, collecting additional data, modifying model input parameters, and then conducting further sensitivity analyses. See *Transcript (Slattery) Vol. VIII* at p. 1515, ln. 10 – p. 1522, ln. 14. For example, sensitivity analyses conducted in Phase 4 disclosed that the model was very sensitive to stream stage (depth) and the depth of drains. With this information, the Proponents had surveys performed to establish stream channel and drain depths to improve the model. And throughout the peer review process and model calibration, the peer reviewers made repeated simulations with the steady-state model and the transient model in which they adjusted model parameters in order to achieve a better match between predictions and observations. Thus, the evidence establishes that extensive sensitivity analyses were, in fact, performed on the Phase 4 groundwater model relied upon by the State Engineer.

369. Both before and during the trial of this case the State Engineer's office was in the process of completing a formal sensitivity analysis for inclusion in the model documentation but had encountered operator-generated problems unrelated to the RGDSS groundwater model that delayed completion of that documentation. The manager of the RGDSS project, Mr. Ray Bennett, explained that due to all of their work with the RGDSS groundwater model, by June 30, 2004, the modelers had detailed knowledge of how sensitive the model was and to what particular parameters. Thus, he testified that a memorandum containing the formal sensitivity analysis was "strictly a documentation exercise." *Transcript (Bennett) Vol. XIV* at p. 2612, ln. 10 - 20. Clearly the better practice, and the one utilized in early phases of the model, was to do a formal sensitivity analysis in addition to the sensitivity analysis which is part and parcel of the calibration of the model. Here, it is undisputed that a newly hired modeler for the State, Dr. Yu, did not do the formal sensitivity run until after June 30, 2004,[49] and then she did it using the SIP solver instead of the LMG solver which had been used by Dr. Schreüder in the model calibration. No one noticed the problem with the solver until the trial was in progress. This fact can be viewed two ways. Protestors pointed to this as evidence that the proper modeling protocol described by Dr. Schreüder was not, in fact, followed. Proponents argued that because of the length of development of the model, the continuous interplay of the calibration and sensitivity analysis, and the two formal sensitivity analyses before Phase 4, the sensitivities of the model were well understood before June 30, 2004; and the formal documentation and study were academic. Bennett testified that:

> Well, we already had done two formal sensitivity analyses; and, as Dr. Schreüder described, every modeler will tell you the calibration process inherently involves sensitivity. During the calibration process, you are adjusting parameters within reasonable ranges; and you're evaluating how the model changes. So by the time Phase 4 rolled around, the modelers had a detailed knowledge of how sensitive the model was and to what particular components. So this memorandum was strictly a documentation exercise.

Transcript (Bennett) Vol. XIV at p. 2612,

370. The Protestors' argument that a formal documented sensitivity analysis was required before a model could be used elevates form over substance. The evidence establishes that comprehensive sensitivity analyses were performed on the RGDSS groundwater model throughout its development. The purpose of that work was to aid the modelers' understanding of the model and to improve its predictions. Those purposes have been accomplished, and nothing is added to the model or the accuracy of its predictions to require that documentation of the sensitivity analysis be completed before the model can be used for its intended purposes under the Rules. Accordingly, the Court will not disapprove the Rules or reject the RGDSS groundwater model simply because the formal documentation of a sensitivity analysis on the RGDSS groundwater model has not been finalized by the State Engineer. That being said, the Court expects the State

[49] Ray Bennett testified the formal sensitivity analysis first performed by Dr. Yu was done from January to June 2005. *Transcript (Bennett) Vol. XIV* at p. 2603.

Engineer to complete this part of the RGDSS groundwater model documentation so that applicants subject to the Rules will be able to better understand the RGDSS groundwater model and its sensitivities. This will also be valuable to outside peer review which hopefully will contribute to the long-term improvement of the RGDSS groundwater model. Moreover, because the State has continued to work on the model since June 30, 2004, the Court anticipates the need to continue the entire process of review and evaluation in the loop described by Anderson and Woessner.

D. Use of a Steady-State Model for Predictive Purposes in the Valley

371. The Protestors' experts testified that a steady-state groundwater model can be used to make reliable predictions about the long-term sustainability of new groundwater development in the Valley. Protestors' Exhibit No. P-1, *Professional Opinion No. 7*. As a general proposition this statement may be correct for an aquifer system that is in a comparative state of equilibrium. The Court finds, however, that the aquifer system in the San Luis Valley is not in a state of equilibrium and that the stresses on the San Luis Valley's aquifers vary significantly seasonally and monthly. The Court found persuasive the contention of Proponents' experts that a steady-state groundwater model will not correctly predict the impacts of new or increased groundwater development from the confined aquifer, and will not correctly predict whether the aquifer system is sustainable. The Court further finds that the steady-state RGDSS groundwater model is not a sufficiently reliable tool to be used to make predictions about the effects of new or increased withdrawals from the Confined Aquifer System in the San Luis Valley because simulations made using that model understate the impacts of such groundwater withdrawals.

372. A steady-state model is not appropriate for predictive purposed in the Rio Grande Basin. See *Transcript (Slattery) Vol. X* at p. 1493. It is very useful for purposes such as the sensitivity analysis.

373. To the extent one wishes to consider the results of steady-state runs for predictive purposes together with other sources, the field data, stream flow, as well as the overwhelming agreement of the water engineers who practice in the San Luis Valley, the data from the model, in fact, supports the conclusion that the confined aquifer is experiencing net storage loss. In other words, it is being mined. State Exhibit RG-25, printed earlier, is the groundwater model budget. It includes data from the steady-state, monthly and average monthly versions of P13 as the initial-period data from 1950-1969.

E. The RGDSS Groundwater Model Was Developed and Operated in a Manner Consistent with Accepted Modeling Techniques and Is Useful and Appropriate for the Purposes for Which It Was Created

374. The Court has tried to describe the development and state of functionality of the RGDSS groundwater model in some detail. The development of the conceptual model and the translation into the inputs for the RGDSS groundwater model were done using the best tools and knowledge available today. While the accuracy of the gradients used in the model was an issue raised by the Protestors, they generally did not fault the

conceptual model. The RGDSS groundwater model was calibrated to both steady-state and transient conditions. The sensitivity analyses were performed for every phase including during the development of the Phase 4 model. The selection of MODFLOW as the base computer program was unchallenged. Similarly, the modeling protocol selected is one generally accepted by all the modelers who testified in the case. The challenges to the way in which the Phase 4 or P13 groundwater model was calibrated and accepted as a converged model with an acceptable mass balance was discussed at length above.

375. In the end, the Court concludes that while the RGDSS groundwater model has much room for improvement, it meets the professional standards of the modeling protocol used, and the Court agrees with the Proponents' experts that this model is ready for the uses for which it was developed. As a basin-wide model used for understanding the region, it is a remarkable, yet obviously imperfect and incomplete accomplishment. That it is imperfect and incomplete is not for lack of investigation and research or skill in modeling. Every effort was made to ensure that the inputs to the model include all reliable real-world data. When the inputs, however, include estimations of such important matters as withdrawals from pumping and when whole areas and layers have only scattered wells with known data, no one should expect the model to be perfect.

376. The difficulties with certain cells in the margins of the domain by Capulin and the Conejos Canyon and the anomalies by La Sauses and Saguache are such that we all understand the model is imperfect. But the flaws are not analytical flaws such as the flaws in the Park County Sportsmen's model rejected by a sister water court and the Supreme Court. The flaws there began with an incomplete conceptual model. There are no such flaws here. During the presentation of evidence in this case, the Court was impressed by the degree of cooperation and collaboration between the various experts involved in the RGDSS Study. The peer review committee and the regular communication between the hydrogeologist, the plant physiologist, field engineers, division engineer and the modelers are particularly important to the development of a good model.[50] The translation of the field data into the inputs for the groundwater model and the setting of the range of adjustment the modeler can use without violating the known real world required communication and understanding. This was done with exceptional care in the development of the RGDSS groundwater model.

377. This section began with a quotation first cited to the Court by Protestors, "All models are wrong, but some models are useful." Clearly, this model has some things "wrong." Equally clearly, it is very useful. A basin-wide groundwater model is indispensable to the administration of the water rights in priority and to compliance with the Rio Grande Compact. A basin-wide groundwater model is also indispensable to the understanding of how to achieve sustainability of the aquifer to protect present and future use of the aquifers. The General Assembly recognized the need to gain a better understanding of the confined aquifer and set in motion the development of the Rio Grande Decision Support System.[51] As already noted, this legislation and the response to it by the State Engineer and the various water interests in the San Luis Valley converted

[50] See McLaughlin, D.B. 1984 *A Comparative Analysis of Groundwater Model Formation* : U.S. Army Corps of Engineers. The Hydrologic Engineering Center

[51] HB 98-1011

the statutory authorization for a "study" into the development of a full-fledged decision support system with both a groundwater model and a surface water model. This Water Court has admitted in evidence other water models in the past. Those models pale in comparison to the Phase 4 model presented here. The RGDSS groundwater model Phase 4 (P13) is the best tool currently available for analysis of groundwater conditions in the San Luis Valley.[52]

378. The Rules anticipate that the RGDSS groundwater model will improve over time both in its ability to generally describe the Basin and the water budget, but also as a predictive model in relation to any particular well or well application. The Court has already separately mandated the use of totalizing flow meters on wells in Water Division 3.[53] More accurate pumping information will instantly improve the model output. Obviously, additional test wells in the Costilla Plain and special study of the area between La Sauses and the San Luis Hills is desirable. It was pointed out that there is a MODFLOW module for evaluation of subsidence which became available after this version of the model was completed. *Transcript (Schreüder) Vol. XI* at p. 2225. It has not been added into the groundwater model as of this time. Since that is an issue that will certainly need to be followed closely, the addition of that module may be desirable.

379. Clearly, none of the flaws or obvious failings of the RGDSS groundwater model warrant rejection of the model by the Court. The model was developed and operated in a manner consistent with accepted modeling techniques. While the experts disagreed on the way in which Dr. Schreüder utilized the mass balance override, his method has been used and was accepted by experts for all the states in the Republican River case, and a model based in this method was approved by the United States Supreme Court in that case. The Protestors' own expert, Mr. McDonald, who criticized the method, was a member of the technical advisory committee that approved this methodology and submitted the model to the United States Supreme Court. While not all modelers are comfortable with the way in which the State modelers, led by Dr. Schreüder, determined that the model was convergent and that the model reached a solution to the question posed, the Court concludes that given the state of the input database, this groundwater model is as good as it can be at present and is appropriate for the uses contemplated by the Rules.

380. Finally, it is obvious from the testimony and from exhibits such as RG-30 and RG-31 that the predictive abilities of the RGDSS groundwater model for an individual well should not be overstated. But the model is useful and usable as a point of beginning for a site specific investigation. Dr. Brendecke described how he recommended use of the groundwater model for the Arkansas River Compact which recognized its limitations as a model.[54] He recognized its errors but saw that it could be useful for long-term estimations. This Court similarly sees the errors and limitations of the RGDSS groundwater model but concludes it clearly is useful for the purposes for which it was designed.

---

52 See more generally Exhibit 9, Brendecke opinions and *Transcript (Brendecke) Vol. XIII* at 2394.

53 2005 CW 12, Water Division 3, Order dated August 1, 2006.

54 *Transcript (Brendecke) Vol. XIII* at 2372.

381. The RGDSS groundwater model is appropriate for drawing general conclusions about the regional aquifer conditions in the Rio Grande Basin and the regional effects of various aquifer strategies.

382. The State Engineer imposed the first moratorium on new wells in the confined aquifer in 1972 because all the information before him at that time suggested that new withdrawals would be harmful to senior appropriators and the administration of the Rio Grande Compact. The evidence before this Court, exclusive of the RGDSS groundwater model, strongly reinforces the correctness of that appraisal. The RGDSS groundwater model also supports this appraisal. The RGDSS groundwater model offers the opportunity to better understand the basin and to begin to explore the alternatives available to optimize water utilization in a sustainable way. If this Court or the Supreme Court were to reject this model, the overwhelming evidence presented in this trial would support continuation of the moratoriums in both aquifers currently in place.

383. Everyday, we watch and rely upon, to a degree, weather forecasts. We all know that the forecasts are often wrong. We understand that the models developed for forecasting weather are less than perfect. No one suggests they should not be used because they are useful and often do provide good forecasts. The weather forecasting models work better with every passing year because the database of field data gets larger and more accurate and because the modelers continue to calibrate and adjust the parameters of those models. The same thing will happen with the RGDSS groundwater model. For all the reasons stated, the RGDSS groundwater model Phase 4 (P13) is appropriate for the uses for which it was intended.

384. Further, the RGDSS groundwater model supports the opinions expressed by various experts that the current withdrawals of water from the aquifers are not sustainable and that the confined aquifer is currently being mined.

385. The Court notes that while the Protestors criticized the admission of the RGDSS groundwater model into evidence and found it unreliable, they also presented evidence on the issue of sustainability based upon their experts' use of the steady-state model. The Court obviously rejects those opinions in finding the model, in fact, supports the conclusion that the confined aquifer is being mined. State Exhibit RG-25, printed earlier, is the groundwater model budget. It includes data from the steady-state, monthly and average monthly versions of P13 as the initial period data from 1950-1969. This exhibit and others such as Exhibit 11, Figure 1, pictured earlier, illustrate that the transient monthly 1970-2002 run of the groundwater model shows an average decline of 58,400 af/yr. The RGDSS groundwater model supports the testimony and known ground measurements indicating a significant decline in storage and supports the imposition of rules and other measures to protect the rights of senior appropriators, the Rio Grande Compact obligation, and the statutory mandate that the management of the water resources become sustainable.