IN RE: NON-BINDING ARBITRATION PURSUANT TO THE FINAL SETTLEMENT STIPULATION, *KANSAS v. NEBRASKA AND COLORADO*, NO. 126 ORIGINAL

BEFORE MARTHA O. PAGEL, ARBITRATOR

EXPERT REPORT OF WILLEM SCHREÜDER, Ph.D.

I, Willem A. Schreüder, state the following:

(1) I understand that my role as an expert, both in preparing this report and in giving evidence, is to assist the arbitrator to understand the evidence or to determine facts in issue. The opinions expressed in my report are my own professional opinions.

(2) I have endeavored in my report and disclosures to be accurate and complete, and have addressed matters that I regard as being material to the opinions expressed, including the assumptions that I have made, the bases for my opinions, and the methods that I have employed in reaching those opinions.

(3) I have been advised by the attorney for the State of Colorado of the disclosure requirements of the rules of the arbitration, and I have provided in my report the information required by those rules. I have not included anything in my report and disclosures that has been suggested by anyone, including the attorney for the State of Colorado, without forming my own independent judgment on the matter.

(4) I will immediately notify, in writing, the attorney for the party for whom I am giving evidence if, for any reason, I consider that my existing report requires any correction or qualification; and, if the correction or qualification is significant, will prepare a supplementary report or disclosure to the extent permitted by the applicable rules of the arbitration.

(5) I have used my best efforts in my report and disclosures, and will use my best efforts in any evidence that I am called to give, to express opinions within those areas in which I have been offered or qualified as an expert by the arbitrator, and to state whether there are qualifications to my opinions.

(6) I have made the inquiries that I believe are appropriate and, to the best my knowledge, no matters of significance that I regard as relevant have been withheld from the arbitrator.

(7) I have disclosed any financial or pecuniary interest that I have in the results of this lawsuit or in any property or rights that are the subject of the lawsuit for which my report and disclosures are being submitted.

Dated this 24th day of May, 2010.

Willem A. Schreüder

I. Statement of Qualifications

I am the president of Principia Mathematica Inc., a firm that specializes in mathematical modeling, and an assistant professor adjunct in the Department of Computer Science of the University of Colorado at Boulder. I hold a Ph.D in Applied Mathematics (Computational Fluid Mechanics) from the University of Stellenbosch, South Africa (1986), and a Ph.D in Computer Science (Parallel Systems) from the University of Colorado at Boulder (2005). My resume is attached.

I was a member of the Modeling Committee that developed the Republican River Compact Administration (RRCA) Groundwater Model. Since the development of the model, I have hosted the RRCA web site and performed the annual runs of the RRCA Groundwater Model for the RRCA in accordance with the Final Settlement Stipulation (FSS) and the RRCA Accounting Procedures and Reporting Requirements.

I have devoted my professional career to mathematical modeling, with a special emphasis on basin scale groundwater flow models. In addition to the RRCA Groundwater Model, I have worked on many basin scale groundwater models, including models of aquifers or aquifer systems in the San Luis Valley (Rio Grande Basin), the South Platte Basin, the Arkansas River Basin, and the Raton Basin in Colorado, and the Carbonate Rock Province in Nevada, California and Utah, among others.

My professional consulting practice has primarily involved working with a team of experts to translate physical reality into a mathematical model of a system that captures the essential behavior of the physical system. In addition to 25 years of field experience in the quantification of agricultural water use in the western United States and in the Republican River Basin in particular, my academic background includes courses in geology, hydrology, physics, chemistry, mathematics and computer science.

I have previously been qualified by Courts as an expert in the areas of mathematics, mathematical modeling, data analysis, fluid dynamics, computational fluid dynamics including ground and surface water modeling, and the interpretations of related data. My opinions in this report are in those same areas.

II. Opinion

My opinion addresses the Colorado Compact Compliance Pipeline (the “Pipeline”), specifically the extent to which the operation of the Pipeline should be represented in the RRCA Groundwater Model (the “Model”).

Opinion: Pumping from wells used to supply water to the Pipeline (the “Pipeline Wells”) should be represented in the Model to determine depletion to stream flows caused by the Pipeline Wells, and the Final Settlement Statement expressly states that depletions from such wells will be computed by the Model

and included in the State's Computed Beneficial Consumptive Use, but outflow from the Pipeline to the North Fork of the Republican River above the stream flow gage at the Colorado-Nebraska state line should ***not*** be represented in the Model.

Basis for the Opinion: Stream depletions caused by the Pipeline Wells cannot be measured, which is why a groundwater model was developed to determine stream depletions from well pumping, and the Model provides reasonable estimates of stream depletions caused by the Pipeline Wells for the purposes of the RRCA Compact Accounting. Outflow from the Pipeline to the North Fork of the Republican River can be measured and is by definition surface flow. The Model only represents baseflow, i.e., the groundwater contribution to stream flow. Incorporating the outflow from the Pipeline in the Model would be improper and could lead to double counting of stream depletions.

III. Introduction

The Republican River Compact (the "Compact") was written with surface water in mind. The Compact allocated water for beneficial consumptive use among the States of Colorado, Nebraska, and Kansas from the computed average annual virgin water supply originating in designated drainage basins that were calculated using a set of surface water gages. At the time the Compact was signed in 1942, this procedure for allocation of water for beneficial consumptive use was appropriate because the amount of groundwater use was minimal. However, even the original Compact contained some compromise. Although the goal of the Compact was to make allocations of water for beneficial consumptive use from the virgin water supply of designated drainage basins, the method of calculating the virgin water supply was limited by the existence of surface water gages, and the practical reality that surface water gages are limited to places along stream channels where an accurate flow measurement can be made.

Based on the Final Settlement Stipulation (FSS), two additional computations were added to the Compact Accounting: stream depletions caused by well pumping and stream flow accretions due to imported water from outside the basin.

As a result of groundwater withdrawals, the amount of flow in the streams in the basin is decreased. In the absence of groundwater withdrawals, typically called well pumping for short, there would have been more flow in these streams. The goal is therefore to determine what the stream flows would have been in the absence of pumping. This is done by estimating the change in stream flows caused by well pumping, which is called the Computed Beneficial Consumptive Use of groundwater ($CBCU_G$) in the RRCA Accounting Procedures. The $CBCU_G$ is a quantity that cannot be measured or reliably estimated from measurements. The only reasonably reliable method for estimating $CBCU_G$ is a groundwater model.

In the northern part of the Republican River Basin, a large volume of surface water is diverted from the South Platte and Platte Rivers. Some of that water

enters the groundwater flow system of the Republican River as seepage from canals or irrigation return flow. This is water imported into the Republican River and Nebraska receives a credit for this water imported into the basin that is not part of the virgin water supply of the basin. The FSS requires that imported water be excluded from the virgin water supply calculation, and consumption of imported water is not be counted as CBCU under the Compact. (FSS, § IV.F). The goal is therefore to determine how much of the gaged flow at streamflow gages used in the Compact accounting is the result of imported water. Again, the only reasonably reliable method for estimating the increase in stream flows from water imported into the basin by Nebraska is a groundwater model.

The States therefore cooperated in the development of the RRCA Groundwater Model (Model). The purpose of the Model is to estimate those quantities that cannot be reliably estimated using measurements. Specifically, the Model is used to estimate the annual $CBCU_G$ and the imported water supply credit that Nebraska is entitled to as the result of water imported into the Basin.

The Model was implemented using the USGS MODFLOW-2000 program. This program is the most widely used groundwater flow program in the world. The Model represents the flow of groundwater using the vertically averaged saturated flow equations, that is, it represents the flow of water between the water table and the bottom of the aquifer. Inflow to the aquifer, such as recharge from applied irrigation water, canal leakage, and precipitation, is applied to the water table. Well pumping from the aquifer and the consumption of groundwater directly from the water table by plants (evapotranspiration) is also represented in the Model.

Quantification of interaction between surface water and groundwater is a key feature of the Model. The MODFLOW stream package is used to track baseflow in surface streams. The Model estimates the flow from the aquifer into surface streams. This flow in a surface stream resulting from groundwater discharge from the aquifer is called baseflow. The Model similarly estimates flows from surface streams to the aquifer. The direction and magnitude of the flow is given by Darcy's law. When the water table is higher than the water level in the stream (called the stage), the stream gains flow from the aquifer, as flow is from the aquifer to the stream. When the stage is higher than the water table, the stream loses flow to the aquifer.

It is important to note that the Model only represents the baseflow of surface streams. In reality, there are other inflows to surface streams, including runoff from precipitation and snowmelt, surface return flows from irrigation (tailwater), and reservoir releases. There are also diversions from streams for irrigation or other uses. These features are not represented in the Model because these quantities are quantified using stream gages or other methods in the RRCA Accounting Procedures. Including these features in the Model would lead to double counting of the depletions or accretions to stream flows caused by these features.

The Model was calibrated in transient mode to the historical period 1918 to 2000. The calibration process established aquifer parameters such as hydraulic

conductivity and specific yield, as well as the relationship between recharge and precipitation, based on estimates of historical well pumping and recharge, observed water levels, and stream gains estimated from gaged flows. Gaged surface flows were analyzed to determine the amount of baseflow in the gaged surface flows, that is the amount of flow attributable to groundwater gains. The stream flow predicted in the Model, which is baseflow, was then compared against the baseflow determined from the gaged surface flows. The Model parameters were adjusted until the Model was able to reproduce the baseflow with a reasonable degree of accuracy.

In the construction of the Model, great care was taken to not double count impacts. Specifically, the Model considers only gains and losses to baseflow. By definition, baseflow is the portion of the flow in surface streams that is attributable to discharge of groundwater into the stream. The balance of the flow in surface streams is attributable to runoff from precipitation events, snow melt, reservoir releases and similar mechanisms.

Thus, the Model only considers depletions to those stream flows that have or would have accrued to the surface streams as baseflow. The reason for representing only baseflow in the Model is that the Compact contains explicit accounting for surface water. The purpose of the Model is only to estimate those quantities that cannot be measured, such as the stream flow depletions as a result of well pumping and stream flow accretions due to imported water. In the case of the reservoirs, some or all of the inflow into the reservoir may be baseflow. However, when this water is released from the reservoir, whether immediately or after being stored, that water is no longer considered baseflow. Instead, the flow is considered surface flow and the amount of surface flow is measured as it is released from the reservoir.

In order to estimate the change in stream flow caused by well pumping and due to imported water, the Model is run in a change mode. The Model is first run using the best estimates of the actual stresses that occurred. This run is called the “base” run in the RRCA Accounting Procedures. The Model is then run a second time. This run is called the “no State pumping” run in the RRCA Accounting Procedures, with the pumping and pumping recharge in one of the states shut off. This typically causes stream flows to be greater. The difference between the Model predicted stream flows in the historical and “no State pumping” runs is the Model estimate of the stream flow depletions, caused by well pumping.

IV. Modeling the Colorado Compact Compliance Pipeline

The Colorado Compact Compliance Pipeline (the “Pipeline”) will deliver groundwater from wells that have historically been used for irrigation to supply new surface flow to the North Fork of the Republican River to offset stream depletions.

For practical reasons, the pumping from all of the groundwater rights retired from irrigation will be concentrated in eight of the wells, the “Pipeline Wells”. Water

pumped from these wells will be conveyed through the Pipeline to a point on the North Fork of the Republican River in Colorado just above the stream flow gage on the North Fork of the Republican River at the Colorado-Nebraska State Line.

Pumping from the Pipeline Wells will continue to cause depletions to stream flows. Just like other stream depletions from well pumping, the stream depletions caused by the Pipeline Wells can only be determined and evaluated using the Model. Therefore, the well pumping from the Pipeline Wells will be included in the Model to determine stream depletions from these wells, as provided in the FSS. The pumping from these wells will treated as fully consumptive as the water will be used to offset stream depletions for Compact compliance purposes.

The $CBCU_G$ resulting from the pumping of the Pipeline Wells will be included in Colorado's Computed Beneficial Consumptive use, as provided in the FSS. Specifically, the pumping from the Pipeline Wells will be included in the “base” run, while the pumping will be removed in the “no Colorado pumping” run. Therefore, the stream depletions caused by the Pipeline Wells will be determined using the Model.

The outflow from the Pipeline to the North Fork of the Republican River will be gaged. Since this flow can be directly measured, there is no need to use the Model to evaluate the fate of this flow. Flow at the North Fork gage will consist of baseflow, surface flow, and Pipeline flow. The Model determines to what extent the baseflow is depleted by well pumping however, the Model is not used to determine depletions to other components of surface flows. Therefore, the Model should not be used to determine depletions to the outflow of the Pipeline to the surface flows of the North Fork of the Republican River for the same reason that releases from reservoirs are not included in the Model.

As a result, no changes to the way that the Model is applied are required to account for the discharge from the Pipeline to the North Fork of the Republican River. The pumping from the Pipeline Wells will be included in the historical pumping. In the “no Colorado pumping” run the pumping from all wells in Colorado, including the Pipeline Wells, are removed and therefore impacts from the Pipeline Wells are included as part of Colorado's $CBCU_G$. But the discharge from the Pipeline should not be included in the Model.

V. Kansas Proposal for Modeling the Pipeline

Kansas proposed a modification to the Model for modeling the outflow from the Pipeline to the North Fork of the Republican River. Kansas' proposal was that in addition to using the Model to determine the stream depletions from the Pipeline Wells, the outflow from the Pipeline should also be incorporated in the Model. This would require that the Model be modified to allow the Pipeline outflow to be added to the Model’s stream network above the North Fork streamflow gage. Under Kansas’ proposal, the gaged outflow from the Pipeline would then be added as inflow to the North Fork in the “base” run. This flow would be tracked down the North Fork to Swanson Reservoir. At that point, the flow would then be removed from the stream network. This flow would then be used in the runs

used to evaluate the impacts of Kansas and Nebraska well pumping and the credit for imported water. However, in the run without the Colorado pumping, the outflow from the Pipeline would also be removed.

The Kansas proposal is flawed for several reasons. First, it uses the Model to evaluate a quantity added to surface streamflow that can be directly measured, which is inconsistent with the way other surface flow changes are handled. Second, it selectively adds this flow between the State Line and Swanson Reservoir, but then fails to track it further downstream. Third, it fails to credit Colorado for all of the water delivered to the North Fork of the Republican River at the Colorado-Nebraska State Line for the benefit of the downstream States.

The outflow from the Pipeline will be gaged and will be included in the gaged flow of the stream flow gage on the North Fork of the Republican River at the Colorado-Nebraska state line. This is surface flow just as the surface flow that would be generated from a rainstorm upstream. The Model does not incorporate changes in the surface flow that is measured at the North Fork gage or any other surface water gages. The reason is that the Compact explicitly considers these measured flows. The Model was intended only for the purpose of estimating those quantities that increase or decrease surface flows that cannot be otherwise measured.

If the outflow from the Pipeline were included in the Model, Colorado would receive only partial credit for the water delivered to the North Fork at the State Line. Depending on the volume of water delivered and the time of year, Colorado would receive credit for less than 80% of the water delivered at the State Line. The reason for the difference is that in essence, Colorado only gets credit for the water that reaches Swanson Reservoir, some 50 miles downstream. In the reach between the State Line and Swanson Reservoir, some of the water is lost due to nearby pumping in Nebraska, evapotranspiration and similar losses. At times, especially during the summer, the river actually dries out along this reach. These are factors outside of Colorado's control, yet the Kansas proposal would only credit Colorado for that fraction of the water that actually reaches Swanson Reservoir. Since the Pipeline outflow will replace stream depletions above the streamflow gage on the North Fork at the state line, it is not appropriate to include this water in the Model in the reach below the gage.

The Kansas proposal is also inconsistent with other accounting in the RRCA Accounting Procedures. For example, 100% of all evaporation losses from reservoirs in Colorado are added to Colorado's CBCU because it is assumed that had that water not evaporated from the reservoir, it would have reached the compact accounting streamflow gage. In the case of Bonny Reservoir, there is more than 40 miles between the Reservoir and the gage, and recent experiences with reservoir releases showed that only a fraction of the water released from the reservoir would actually reach the gage. However, the Compact assumes that this is 100% of the evaporation from Bonny is added to Colorado's CBCU, which implies that all of that water would have reached the gage or have been put to beneficial use before it reached the gage and hence accounted for.

In the case of the Pipeline deliveries, water delivered to the North Fork of the Republican River at the state line is available to be put to beneficial use by Nebraska at the state line and will replace stream depletions calculated above the gage. Beyond the state line Colorado has no control over how Nebraska chooses to use its allocation under the Compact.

For example, the State of Nebraska may choose to divert 100% of the Pipeline deliveries one foot from the state line. Such a surface diversion would be accounted for in the surface water accounting under the Compact. However, this would not be represented in the stream network of the RRCA Groundwater Model because the Model considers only baseflow and does not represent diversions. However, under the Kansas proposal, that flow would still be included in the Model and only the fraction of the water that reaches Swanson Reservoir would be credited to Colorado.

VI. Accuracy of the Model

The Model is used to estimate depletions to stream flows due to well pumping and accretions to stream flows due to water imported into the basin by Nebraska that recharges the groundwater system – quantities that cannot be measured. The Model is not perfect, but provides a reasonable method for estimating these quantities. However, the key is that the Model should only be used to estimate those quantities that cannot be directly measured.

Where the Model is used, it should be borne in mind that the Model was calibrated in transient mode to the period 1918-2000, with the intent that it would be used to evaluate annual total $CBCU_G$ and imported water. The Model has not been demonstrated to be reliable on a shorter time scale. In fact, it is my opinion that the Model results are not sufficiently accurate that they could be used on a monthly basis to determine the time, location, and amount of stream flow depletions.

The purpose of the Model is to estimate the depletions to stream flows caused by well pumping and to estimate the accretions to stream flows due to water imported into the basin in Nebraska. Application of the Model for other purposes is not appropriate. Specifically, it is inappropriate to add a surface water inflow such as the Pipeline to the baseflow represented in the Model because the Model was not designed to or intended to represent surface water changes that can be measured.

VII. Conclusion

I base the foregoing opinions on my general knowledge of the Republican River Basin and the Compact Compliance Pipeline, the RRCA Groundwater Model, and my modeling knowledge and expertise. Any specific data that I considered for this report will be posted at *http://www.prinmath.com/ccp.*

My qualifications, a list of all publications authored by me in the previous 10 years, a list of all other cases in which, during the previous four years, I have testified as an expert at trial or by deposition are, and my rate of compensation also attached. My compensation is not dependent upon nor affected by the outcome of this matter.

Willem A. Schreüder, Ph.D

President and Principal Scientist, Principia Mathematica Inc.

Specialist in Applied Research and Development Activities in Mathematical Modeling and Computational Fluid Dynamics, including Groundwater Modeling.

Expertise: Mathematical Modeling; Advanced Data Analysis; Numerical Analysis; Computational Fluid Dynamics; Ground and Surface Water Hydrology; Contaminant Transport; Turbulence Modeling; Heat and Mass Transport; Software Development for Data Analysis, Mathematical Modeling, Computer Graphics and Geographical Information Systems (GIS); Solution of Differential Equations; Operations Research; Graphical Presentation of Information; Litigation Support and Expert Witness Testimony.

Billing rate: $140/hour

Expert Witness Testimony

1. Rio Grande Silvery Minnow, et al. vs. John W. Keys, III et al. Case No. CIV 99-1320 JP/RLP-ACE
2. Concerning the Application for Water Rights of Park County Sportsmen's Ranch LLP in Park County, Colorado Case No. 96CW014
3. Rules Governing New Withdrawals of Groundwater in Water Division 3 Affecting the Rate or Direction of Movement of Water in the Confined Aquifer, Case No. 04CW024.
4. ECCV Northern Project Case No. 02CW403
5. Republican River Compact Arbitration before Mr. Karl Dreher Pursuant to Section VII, Final Settlement Stipulation (2009)
6. Cherokee Metropolitan District Upper Black Squirrel Creek Designated Basin Alluvial Aquifer Replacement Plan, Case No. 08GW71.
7. Concerning the Office of the State Engineer's Approval of the Plan of Water Management for Special Improvement District No. 1 of the Rio Grande Water Conservation District, Case No. 2007CW52.
8. In the Matter of Rules and Regulations for the Determination of the Nontributary Nature of Ground Water Produces through Wells in Conjunction with the Mining of Minerals, 2 CCR 402-17
9. Colorado Ground Water Commission hearing on amendment of Rule 5.2.5.2 – Closing Hay Gulch subbasin of Lost Creek Designated Groundwater Basin 09-GW-12.

ACADEMIC BACKGROUND

B.Sc (1981), University of Stellenbosch. Physics III, Chemistry III, Mathematics III, Applied Mathematics III and Computer Science III.

Hons. B.Sc (1982), University of Stellenbosch. Applied Mathematics.

M.Sc (cum laude) (1984), University of Stellenbosch. Applied Mathematics.

Ph.D (1986), University of Stellenbosch. Applied Mathematics, Computational Fluid Dynamics.

Visiting Assistant Professor of Mathematical Sciences (1986-1987), Rensselaer Polytechnic Institute.

Assistant Professor of Mathematics (1987-1989), West Virginia University.

MS (1998), University of Colorado at Boulder. Computer Science.

Ph.D (2005), University of Colorado at Boulder. Computer Science, Parallel Systems.

Instructor (2006-2008), University of Colorado at Boulder, Computer Science.

Assistant Professor Adjunct (2008-), University of Colorado at Boulder, Computer Science.

PROFESSIONAL EXPERIENCE

9/2001 - Present: President, Principia Mathematica Inc.
11/1997 – 8/2001: Senior Engineer/Scientist, Principia Mathematica Inc.
Responsible for data analysis and mathematical modeling related to groundwater flow and transport. Projects include:

1. Peer review and development of the Rio Grande Decision Support System (RGDSS) Groundwater Model;
2. Development and maintenance of the Republican River Compact Administration Groundwater Model, resulting from litigation before the U.S. Supreme Court between the States of Colorado, Kansas and Nebraska;
3. Evaluation of the Park County Sportsman's Ranch application which involved groundwater modeling to support an underground storage project;
4. Lockheed-Redlands project which involved basin-scale groundwater fate and transport modeling and data analysis.
5. Peer review and development of the East Snake Plane Hydrologic Model

Responsible for data analysis and mathematical modeling related to surface water. Projects include:

1. Evaluation of the Truckee River Operations Model (TROM) in California and Nevada;
2. Evaluation of the Upper Rio Grande Water Operations Model (URGWOM) as part of the Silvery Minnow litigation.

Responsible for data analysis and mathematical modeling related to atmospheric modeling. Projects include:

1. Evaluation of plume condensation at BASF facility, Port Arthur, TX;
2. Atmospheric dispersion modeling to evaluate the impacts of the Ingram Barge incident, Baton Rouge, LA;
3. Evaluation of hexavalent chromium exposure from cooling towers at the PG&E Kettleman facility.

Responsible for mathematical modeling, model evaluations and data analysis in several projects involving complex soils and ground water contamination. Projects include:

1. Houston Research Tract;
2. Long Beach Terminal.

Responsible for development and maintenance of mathematical model software and software for data

analysis and graphics.

2/1995 – 10/1997: Senior Engineer, Principia Mathematica Division of Terranext.
Responsible for development of advanced methods of site characterization, evaluation of soil and groundwater contamination, design and optimization of remediation options, atmospheric and groundwater modeling and data analysis. Specific issues addressed included interfacing with laboratories, data validation, integration of GIS and GPS technology into the database and field campaigns, interpretation and modeling of free product contamination, and bioremediation.

Responsible for data analysis and modeling in projects related to soil and groundwater contamination. Projects included:
1. Eugene Rail Yard in Eugene, Oregon;
2. Taylor Rail Yard in Los Angeles, California;
3. Los Angeles Transportation Center in Los Angeles, California;
4. Former Northeast Petroleum Terminal in Tiverton, Rhode Island.

Responsible for air quality data analysis and mathematical modeling related to atmospheric transport at several sites. Projects included:
1. Data analysis and modeling of hexavalent chromium releases from the Gas Compressor Station located at Hinkley, California. This project was dramatized in the motion picture *Erin Brockovich*.
2. Data analysis and modeling of formaldehyde and particulate matter releases from the Willamette plant near Gifford, Arkansas
3. Data analysis and mathematical modeling of air quality at an aircraft manufacturing facility located in Burbank, California;
4. Data analysis, modeling and operational analysis of plume condensation at a geothermal power plant in Kakkonda, Japan.

Responsible for development and maintenance of mathematical model software and software for data analysis and graphics.

1/1990 – 2/1995: Project Engineer, Principia Mathematica Inc.
7/1989-12/1989: Staff Engineer, Principia Mathematica Inc.
Responsible for data analysis and mathematical modeling related to groundwater flow and transport. Projects include:
1. Development of a groundwater model of the Lowry Landfill Site. The model included complex three-dimensional flow and transport of ten different compounds, including simultaneous simulation of five reacting compounds.
2. Development of a groundwater model in the Arkansas River Basin resulting from litigation before the U.S. Supreme Court Litigation between Colorado and Kansas.
3. Development of a groundwater model and evaluation of other groundwater models in the San Luis Valley, Colorado for the AWDI litigation, which involved an application for water rights.
4. Evaluation of groundwater flow and transport models in the Honey Lake Valley in California and Nevada as part of an EIS.
5. Development of a groundwater flow and transport model for the Remedial Action Plan at the Anoka Landfill Superfund Site in Minnesota. A Decision Support System (DSS) was developed and successfully defended before State regulatory agencies.
6. Forensic data analyis and modeling of groundwater and water chemistry to evaluate flooding at the IMC Esterhazy Mine.
7. Data analysis, model development and evaluation for a water rights dispute in Nevada.

8. Senior consultant to Waste Management of North America Inc. on data analysis and mathematical modeling. Specific projects included data analysis and model development for at the Cortese Landfill in New York, the WDI Landfill in New Jersey and the Durham Road landfill in California.

Responsible for the development and maintenance of software for mathematical modeling, data analysis and graphics. Specific items include:

1. Enhancement and maintenance of the PM-TARGET series of ground water flow and heat and mass transport model programs for saturated and unsaturated flow flow and transport in one, two and three dimensions;
2. Enhancements to the USGS MODFLOW groundwater flow program;
3. Development and maintenance of the PM-MODTAR program that permits simultaneous multi-compound reactive transport to be simulated;
4. Enhancement and maintenance of PM-DIAMOND, an advanced systems for the analysis of multi-dimensional models and data, and production of device-independent graphics.

Primary responsibility for analysis and evaluations of large volumes of complex precipitation, surface topography, hydrologic and geologic data, and developing new techniques specifically for this purpose.

Presented and led several scientific workshops on advanced data analyses, numerical modeling of ground water flow, contamination transport and remediation using the MODFLOW and PM-TARGET series of programs as well as the complete suite of Principia graphics packages.

8/1987-5/1989: Assistant Professor of Mathematics, West Virginia University.
Teaching undergraduate and graduate courses in Calculus, Differential Equations and Numerical Analysis. Research on the numerical prediction of highly non-linear diffusion processes, and numerical prediction of atmospheric flows. As part of both of the above research projects, fundamental research was conducted on automatic grid refinement in parabolic and elliptic problems.

9/1986-6/1987: Visiting Assistant Professor of Mathematical Sciences, Rensselaer Polytechnic Institute.
Teaching Numerical Analysis. Research in conjunction with Prof. Georges Belfort of Chemical Engineering and Prof. Donald Drew of Mathematical Sciences Department on the numerical prediction of pulsating flow in ultra-filtration membrane systems.

1/1986-7/1986: Scientific Computing Specialist, Bureau of Mechanical Engineering, University of Stellenbosch.
Responsible for development of data acquisition system on towing tank; enhancement of ADINA finite element package, including development of graphical pre- and post-processing packages; development of VT 100/Tektronix 4010 terminal emulation software; supervising operation of VAX minicomputers; development of a routing and scheduling program for a fleet of containerized cargo vehicles; supervising development of software for a 4 axis flight simulator.

1/1985-12/1985: Captain Pilot, Wellington Air Services.
Flying charters in southern Africa. Command pilot on AC 112, PA 28-200R and PA 28-260, co-pilot on BE 54 and BE 58 aircraft.

SELECTED PUBLICATIONS:

Schreüder, W.A. (1984) **Numerical Prediction of Laminar Cross-Stream Jet Flow**. M.Sc. thesis, University of Stellenbosch.

du Plessis, J.P., W.A. Schreüder and M.R. Collins (1985) **Numerical Prediction of Dry Air Flow at Cooling Installations**. Report TW 85-2, Department of Applied Mathematics.

Schreüder, W.A. (1986) **Air Flow About a Directly Air-Cooled Heat Exchanger.** Ph.D. thesis, University of Stellenbosch.

Schreüder, W.A. and Esbeth van Dyk (1988) **Multidimensional Scaling of Qualitative Pair-wise Comparisons.** *Proceedings of 8'th MCDA Conference*, Manchester, pp. 70-77.

J.L. Moseley, H. Yu, W.A. Schreüder and W.Y. Kerr (1989). **Numerical Solutions for Particle Size Distribution in a Fluidized Bed Gasifier.** *Proceedings of the 20'th Conference on modeling*, Pittsburgh.

Schreüder, W.A. and J. Prieur du Plessis (1989). **Simulation of Air Flow About a Directly Air Cooled Heat Exchanger.** *Building and Environment*, **24** 1, pp. 223-235.

Schreüder, W.A. J. Prieur du Plessis and Devraj Sharma (1990). **On the Numerical Treatment of Atmospheric Boundaries.** *Numerical Heat Transfer* **17** 2, pp. 171-196.

Schreüder, W.A. and J. Prieur du Plessis (1990) **On the Numerical Treatment of Interior Boundaries.** *Numerical Heat Transfer* **17** 2, pp. 197-215.

Cole, S.E., D. Sharma and W.A. Schreüder (1994) **A Modern, Refined Application of a Ground Water Flow Model to the Arkansas River basin.** *Proc. 1994 Groundwater Modeling Conference*, Fort Collins, Colorado, August 10-12, pp. 385-393.

Schreüder, W.A. and D. Sharma (1994). **Unsaturated Flows Within layered Materials Used as Liners for landfills and Impoundments -Important Concepts and Predicted Results.** *Proc. 1994 Groundwater Modeling Conference*, Fort Collins, Colorado, August 10-12, pp. 469-477.

Schreüder, W.A., Steven E. Cole and D. Sharma (1996) **Complex Coordinate-System Transformations: Data in South-Central Nevada,** *Proceedings of 6'th Annual Devils Hole Workshop*, Death Valley, California.

Schreüder, W.A. (1997) **On Contouring Surfaces.** Principia Mathematica Technial Note PM-TN-1997-1.

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