Evaluation of HDR/SAWS Modeling of the Carrizo-Wilcox Aquifer in Lee, Bastrop, and Milam Counties, Texas

George Rice
November 2001

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Introduction

This is an evaluation of groundwater modeling performed by HDR Engineering, Inc. (HDR) for the San Antonio Water System (SAWS). The purpose of the modeling was to estimate drawdowns in the Carrizo-Wilcox Aquifer as a result of pumpage associated with the proposed transfer of water to San Antonio[1]. The model does not address the effects of pumpage on the flow of springs and streams.

This evaluation is based on examination of HDR model input and output files, as well as independent runs of the model[2].

Background

The study area is in Central Texas (figure 1). HDR used the computer code MODFLOW[3] to simulate the effects of increased pumpage from the Carrizo-Wilcox Aquifer. The model simulates flow in five hydrogeologic units: undifferentiated "younger' strata, the Carrizo Aquifer, the Calvert Bluff Formation, the Simsboro Aquifer, and the Hooper Formation (figure 2). The model uses artificial boundaries. The southwest and northeast boundaries of the study area are treated as no-flow boundaries. The southeast boundary is treated as a constant head (no drawdown) boundary. The northwest boundary is a natural no-flow boundary that represents the Midway Group; a relatively impermeable unit that is not part of the Carrizo-Wilcox Aquifer.

HDR simulated two groundwater withdrawal scenarios: 55,000 ac-ft/yr and 75,000 ac-ft/yr[4]. This evaluation focused on the 55,000 ac-ft/yr scenario.

The HDR model is a modification of a model produced by Dutton[5]. HDR describes the modifications as follows: *"The major modifications included representing recharge in the outcrop area as leakage, improving calibration in the ALCOA[6] and CPS well fields area, and changing the units from Metric to English."*[7]. However, the drawdown estimates produced by the HDR model are significantly less than those produced by the Dutton model[8]. A comparison of drawdowns predicted by the two models is presented in appendix A.

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[1] See HDR, 1999 and HDR, 2000. All documents mentioned in this report are listed in the reference section.
[2] Mike Thuss of SAWS provided input and output files for the HDR model. Troy Dorman and Larry Land of HDR provided information concerning their simulations and modifications of the model. Independent runs performed by George Rice.
[3] McDonald and Harbaugh, 1988.
[4] HDR, 2000, page 2-10.
[5] Dutton, 1999.
[6] The HDR model does not simulate drawdown in the Alcoa well field area (Sandow Mine area) as well as the Dutton model does. See discussion of problem 2 below, and Appendix C.
[7] HDR, 2000, page 2-3.
[8] The Dutton model is discussed in this report only because HDR used it as a basis for their model, and claim to have improved upon it. This report is not meant to be a defense or a criticism of the Dutton model.

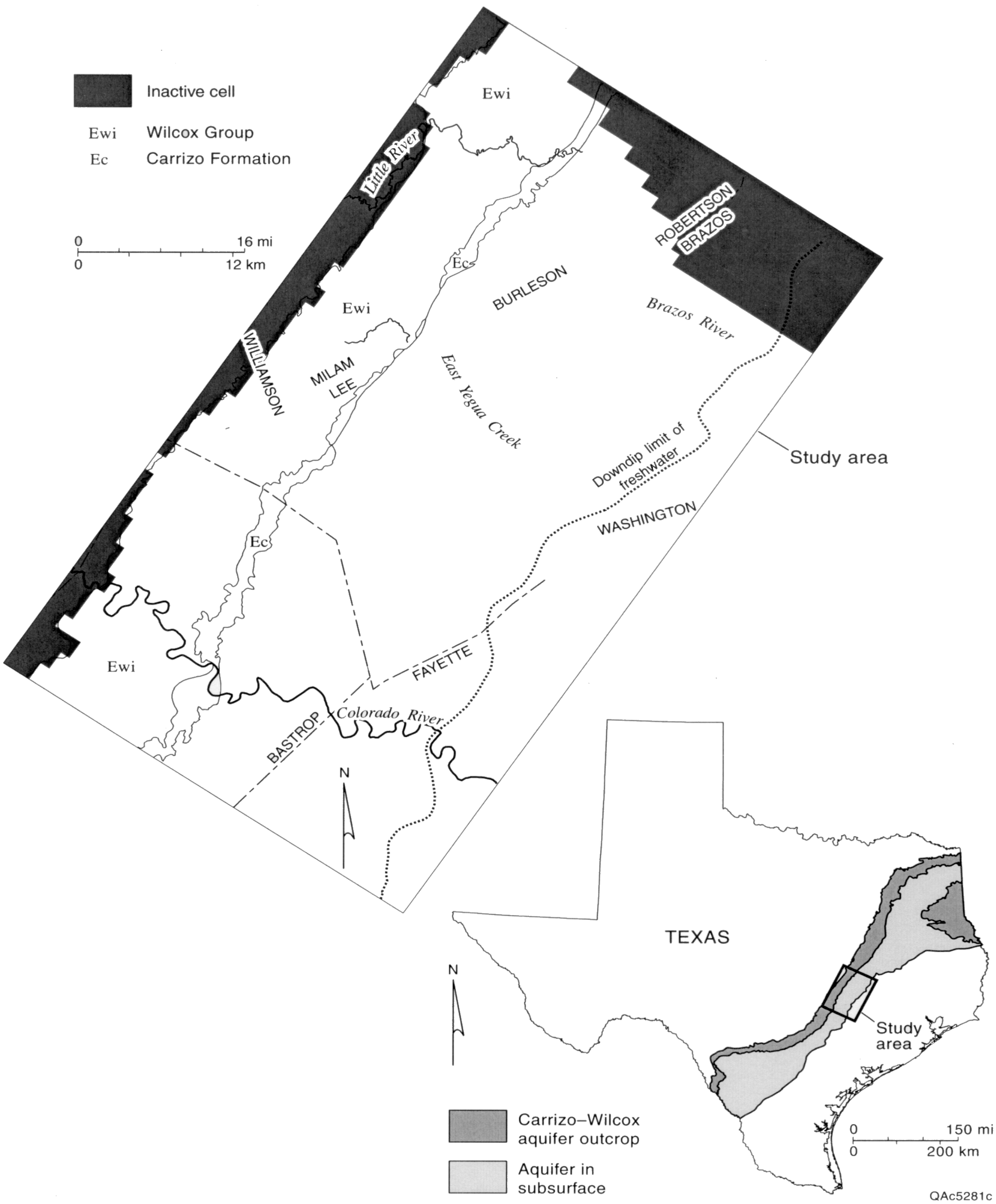

Figure 1

Carrizo-Wilcox Aquifer in Central Texas.
(Adapted from Dutton, 1999)

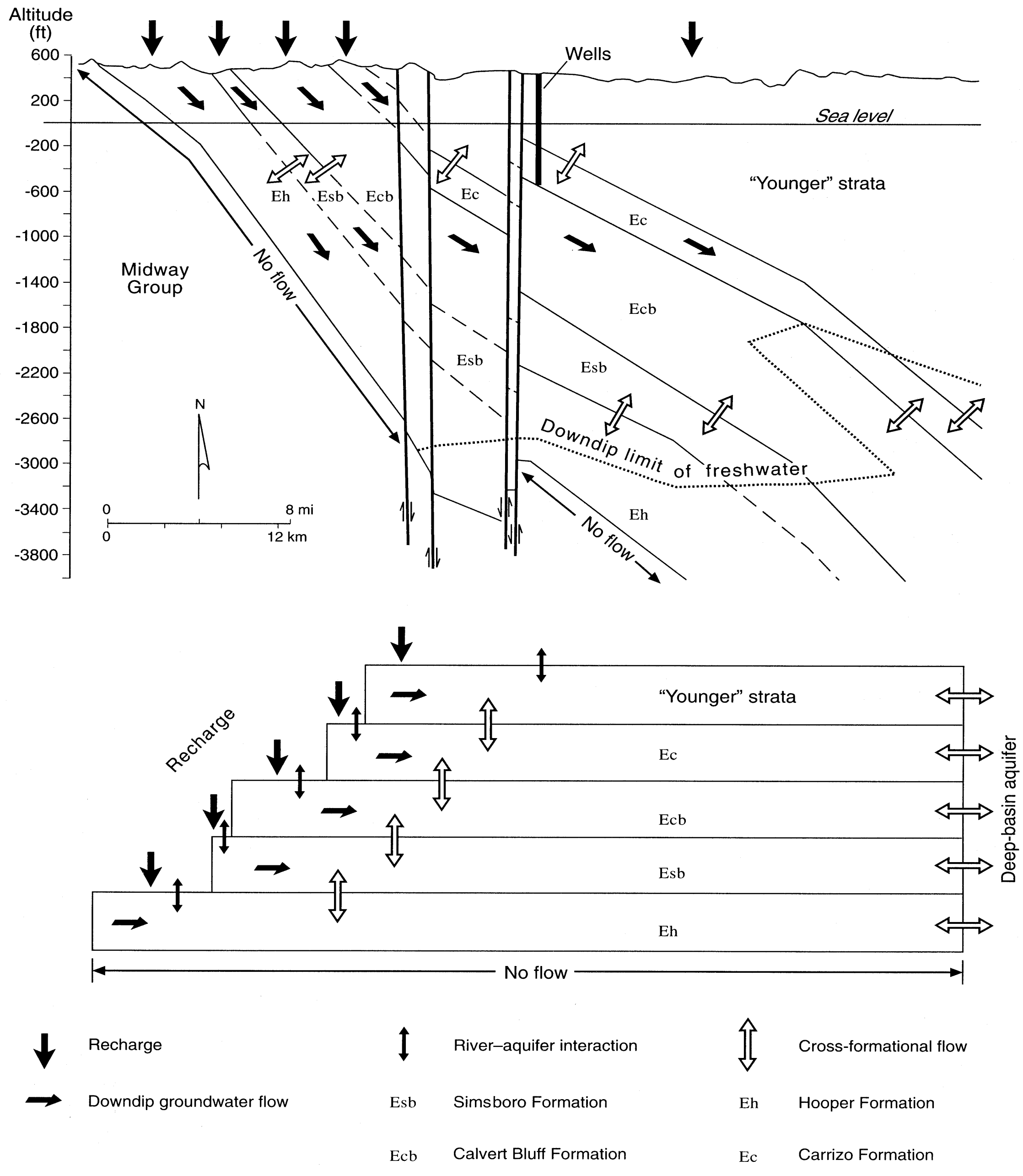

Figure 2

Hydrogeologic Units in Model
(Adapted from Dutton, 1999)

Problems with the HDR Model

Four major problems were identified:

1. Unrealistic recharge rates

2. Underestimation of historic drawdowns

3. Rising water levels in the Carrizo Aquifer

4. Drawdowns intercept artificial boundaries

Each of these problems is discussed below.

1. Unrealistic recharge rates

The HDR model uses constant head cells to apply recharge to the outcrop of each hydrogeologic unit below the "younger" strata. This causes recharge rates to increase as water levels in the outcrop areas decline. According to HDR, this increase in recharge rates is realistic because it represents the capture of water that is lost to springs, streams, and evapotranspiration when water levels are higher[9]. However, this method has resulted in unrealistic rates of recharge. The amount of recharge applied to some parts of the Simsboro Aquifer is more than 20 in/yr. This is more than half of the average annual rainfall of 36 in/yr[10]. In one case, the applied recharge is more than 200 in/yr. Previous investigators have estimated recharge to range from 1 in/yr to 4 in/yr[11]. Appendix B contains a table of recharge rates applied by HDR and sample recharge calculations.

2. Underestimation of historic drawdowns

The HDR model under-estimates drawdowns that have already occurred. In some cases the model under-estimates measured (historic) drawdowns by a factor of more than three[12]. The drawdown estimates are also significantly less than those produced by the Dutton model. The table below compares selected historic drawdowns to those estimated by the HDR and Dutton models. Figures in appendix C compare historic drawdowns in the Simsboro Aquifer to drawdowns estimated by the HDR model.

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[9] Troy Dorman and Larry Land of HDR, personal communication, 12 July 2000.
[10] HDR, 2000, page 2-4.
[11] Dutton, 1999, page 8.
[12] Historic drawdowns taken from static water level data in Alcoa, 2000, Appendices A and B.

Table 1
Comparison of Historic and Modeled Drawdowns

Well ID[13]	Measurement Period	Historic Drawdown (static, ft)	HDR Estimated Drawdown (ft)	Dutton Estimated Drawdown (ft)
59-25-4C5, David Cork	4/88 – 12/99	156	50	71
59-25-5A6, Emory Crump	3/88 – 12/99	118	41	60
SS-15	1/88 – 2/00	109	35	50

The maximum drawdown predicted anywhere in the Simsboro Aquifer through 1999 by the HDR model is 60.6 ft. The maximum drawdown predicted by the Dutton model through 1999 is 95.0 ft.

3. Rising water levels in the Carrizo Aquifer

The HDR model predicts that water levels over most of the Carrizo Aquifer will rise between the years 2000 and 2040. This rise is predicted to occur even though pumpage increases from 3800 acre-feet/yr in 2000, to 5300 acre-feet/yr in 2040. Figures showing the increases in water levels and pumping rates are presented in appendix D.

4. Drawdowns intercept artificial boundaries

Artificial boundaries have been used along the northeast, southwest, and southeast sides of the model. The northeast and southwest sides are no-flow boundaries. The southeast side is a constant head (no drawdown) boundary. Artificial boundaries are appropriate if they are far enough away from the area of interest that they do not significantly affect the results of the simulations. However, the drawdowns predicted by the HDR model intercept the no-flow boundaries, and approach the constant head boundary (figure A-4). This distorts predicted drawdowns. In some areas of the model drawdowns are probably over estimated, while in other areas drawdowns are probably under estimated.

This problem is different from those discussed above. It is a result of the design of the model itself, rather than a result of inappropriate input. The first three problems discussed above could be corrected by altering model input. To correct this boundary problem, the model itself may have to be redesigned. At a minimum, HDR should perform simulations to determine the sensitivity of the model to the artificial boundaries[14]. The accuracy and

[13] 59-25-4C5 and 59-25-5A6 are state well numbers. SS-15 is an Alcoa well identifier. All of these wells are near Alcoa's Sandow mine.

[14] The following is from Mercer and Faust, 1986: "*Note that where it is impractical to include one or more physical boundaries (e.g., an alluvial valley that may be extremely long), the grid can be expanded to an artificial boundary. The artificial boundary should be located far enough from the project area so that it will have negligible effect on the area of interest during the simulation period, but can be much closer than the physical boundary. In this case, the boundary condition is arbitrary (e.g., impermeable conditions), <u>but the influence of the artificial boundary should be checked by comparing the results of two simulation runs using different artificial boundary conditions.</u>* "Emphasis added.

usefulness of the model must be considered suspect until questions regarding the effects of the boundaries are resolved[15].

Conclusion

Predictions of drawdown produced by the HDR model are unreliable. The model should not be used for any purpose until the problems discussed above are corrected.

Review

In June 2001 a draft of this evaluation was submitted to the following people and organizations for comment.

Dr. Alan Dutton
Research Scientist
Bureau of Economic Geology, University of Texas

Eugene Habiger
President/CEO
San Antonio Water System

Robert Harden
R W Harden & Associates, Inc.

Ridge Kaiser
R W Harden & Associates, Inc.

Dr. Robert Kier
RSK Consultants

Larry Land
HDR Engineers Inc.

Only Mr. Habiger of SAWS provided formal written comments. These comments, as well as subsequent correspondence, are presented in Attachment 1.

[15] See discussion of model boundaries in Dutton, 1999, page 40.

References

Alcoa Inc., 2000, *Report on Underburden Pumpage Systems at Sandow Mine for 1999*, R.W. Harden & Associates, Inc., April 2000.

Dutton, A. R., 1999, *Assessment of Groundwater Availability in the Carrizo-Wilcox Aquifer in Central Texas – Results of Numerical Simulations of Six Groundwater-Withdrawal Projections (2000 – 2050),* University of Texas, Bureau of Economic Geology, Report of Investigations No. 256, April 1999.

HDR Engineering Inc., 1999, *Assessment of Groundwater Availability on CPS Property in Bastrop and Lee Counties, Texas*, July 1999.

HDR Engineering Inc., 2000, *Preliminary Feasibility of Options to Deliver ALCOA/CPS Groundwater to Bexar County*; January 2000.

McDonald, M.G., and Harbaugh, A.W., 1988, A *Modular Three-Dimensional Finite-Difference Ground-Water Flow Model,* United States Geological Survey.

Mercer, J.W., and Charles R Faust, C.R., 1986, *Ground-Water Modeling*.

Appendix A

Comparison of Predicted Drawdowns
Dutton Model and HDR Model

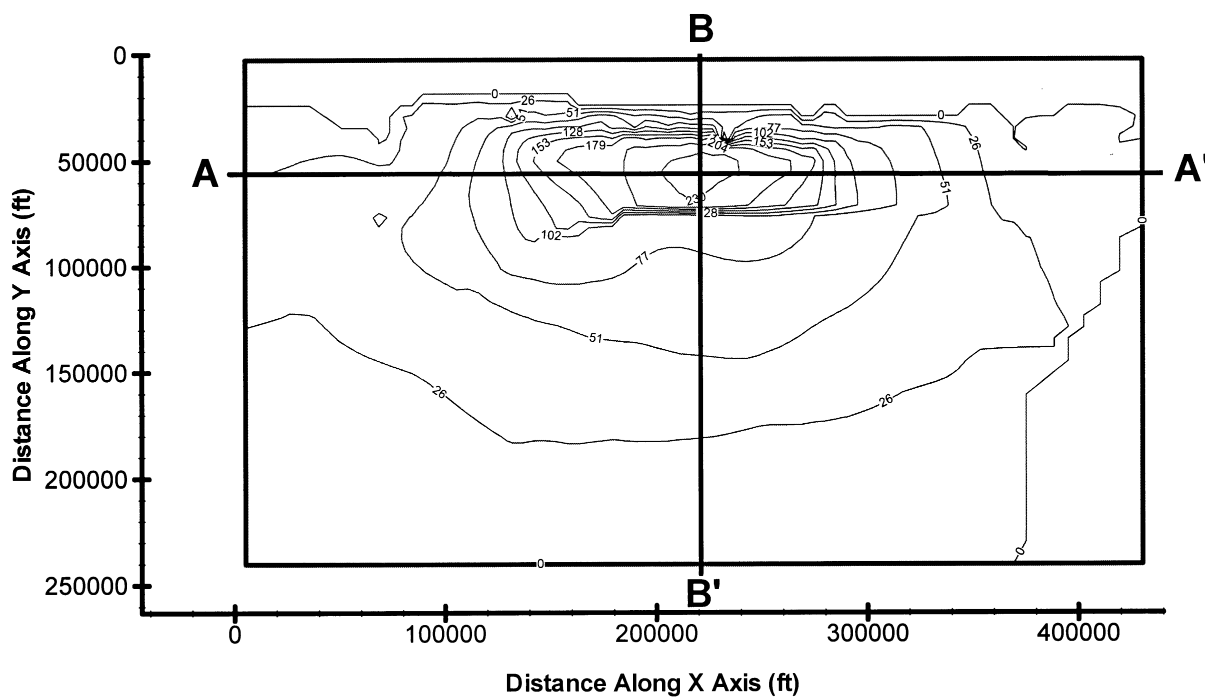
Dutton and HDR did not model identical withdrawal scenarios. Dutton predicted drawdowns for five withdrawal scenarios. The pumping rates ranged from approximately 49,000 ac-ft/yr to 258,000 ac-ft/yr[16]. HDR predicted drawdowns for two withdrawal scenarios with pumping rates of 55,000 ac-ft/yr and 75,000 ac-ft/yr. In order to compare like scenarios, the pumpage scheme in Dutton's model was replaced by HDR's 55,000 ac-ft/year pumpage scheme. That is, the well locations, pumping rates, and pumping schedules in the Dutton model were removed and replaced with those from the HDR model. No other changes were made to the Dutton model input.

Figures A-1 through A-3 illustrate drawdowns predicted for the year 2040 by the Dutton model with the HDR pumpage scheme. Figures A-4 through A-6 illustrate drawdowns predicted for the year 2040 by the HDR model. The HDR model predicts significantly lower drawdowns than the Dutton model. The maximum drawdown predicted by the HDR model for the year 2040 is 112 feet. The maximum drawdown predicted by the Dutton model for the year 2040 is 239 feet.

In figures A-1 and A-4, the top and bottom of the drawdown plot correspond to the northwest and southeast boundaries of the study area, respectively (see figure 1). The left and right sides of the plots correspond to the southwest and northeast boundaries. The cross sections A-A' and B-B' pass through the area of greatest drawdown predicted by each model. The area of greatest drawdown predicted by the HDR model is approximately 12 miles southwest of the area of greatest drawdown predicted by the Dutton model.

[16] Dutton, 1999, page 1.

Drawdown in Simsboro Aquifer (ft) - 2040
Dutton Model With HDR Pumping Scheme For 55,000 ac-ft/yr Scenario



C:\HDRFiles\HDR-DUTTON Hybreds\Hybred-1Tcpk-PCGSim2040PCG1-Profile.lay

Figure A-1

Profile A - A', Drawdown in Simsboro Aquifer (ft) - 2040
Dutton Model With HDR Pumping Scheme For 55,000 ac-ft/yr Scenario

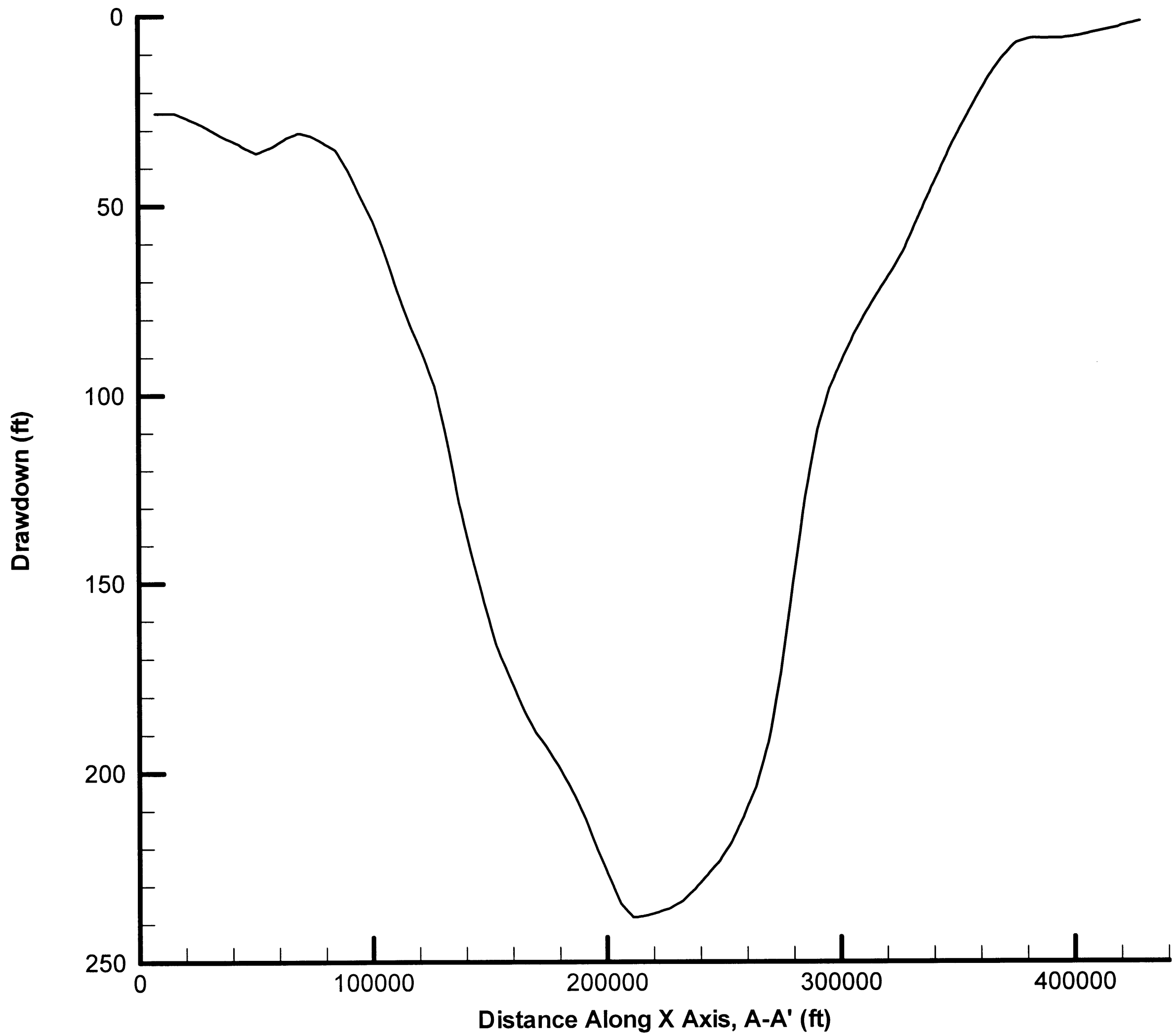


Figure A-2

Profile B - B', Drawdown in Simsboro Aquifer (ft) - 2040
Dutton Model With HDR Pumping Scheme For 55,000 ac-ft/yr Scenario

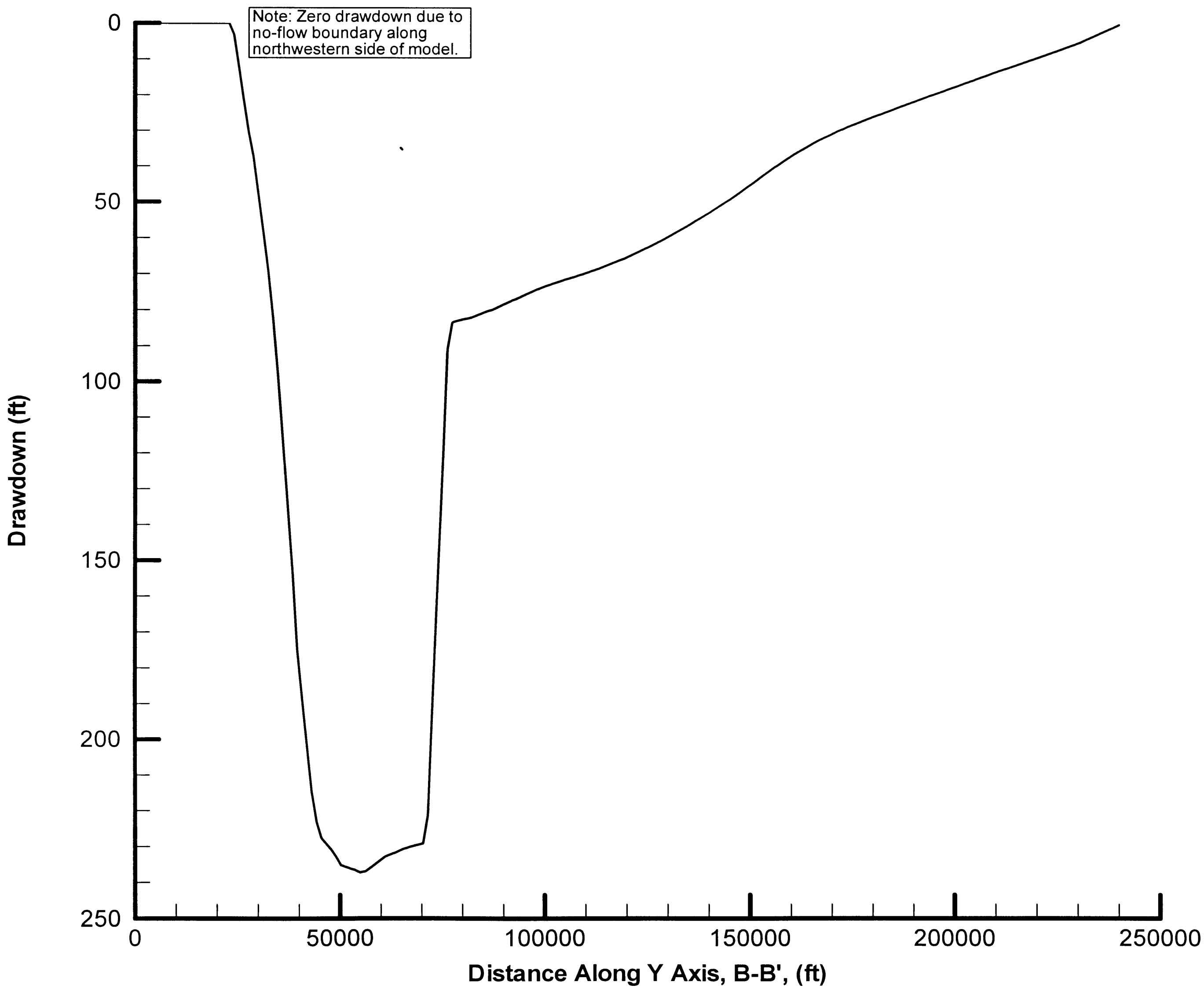


Figure A-3

Drawdown in Simsboro Aquifer (ft) - 2040
HDR Model, 55,000 ac-ft/yr Scenario

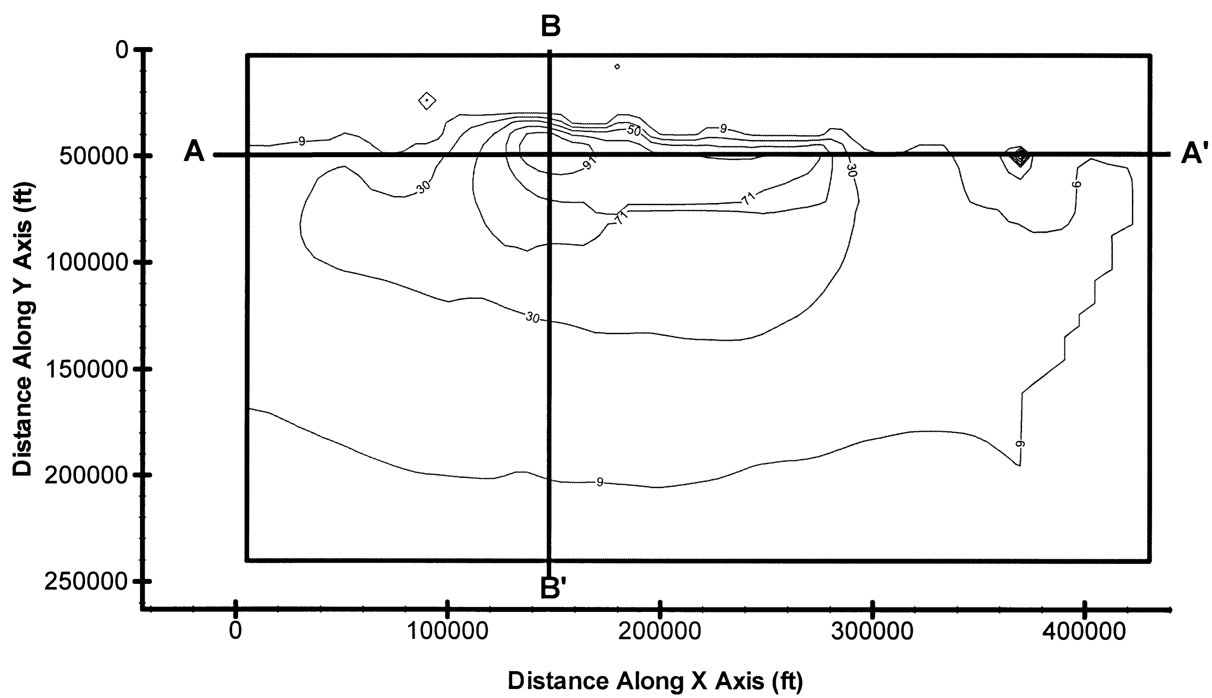


Figure A-4

Profile A - A', Drawdown in Simsboro Aquifer (ft) - 2040
HDR Model, 55,000 ac-ft/yr Scenario

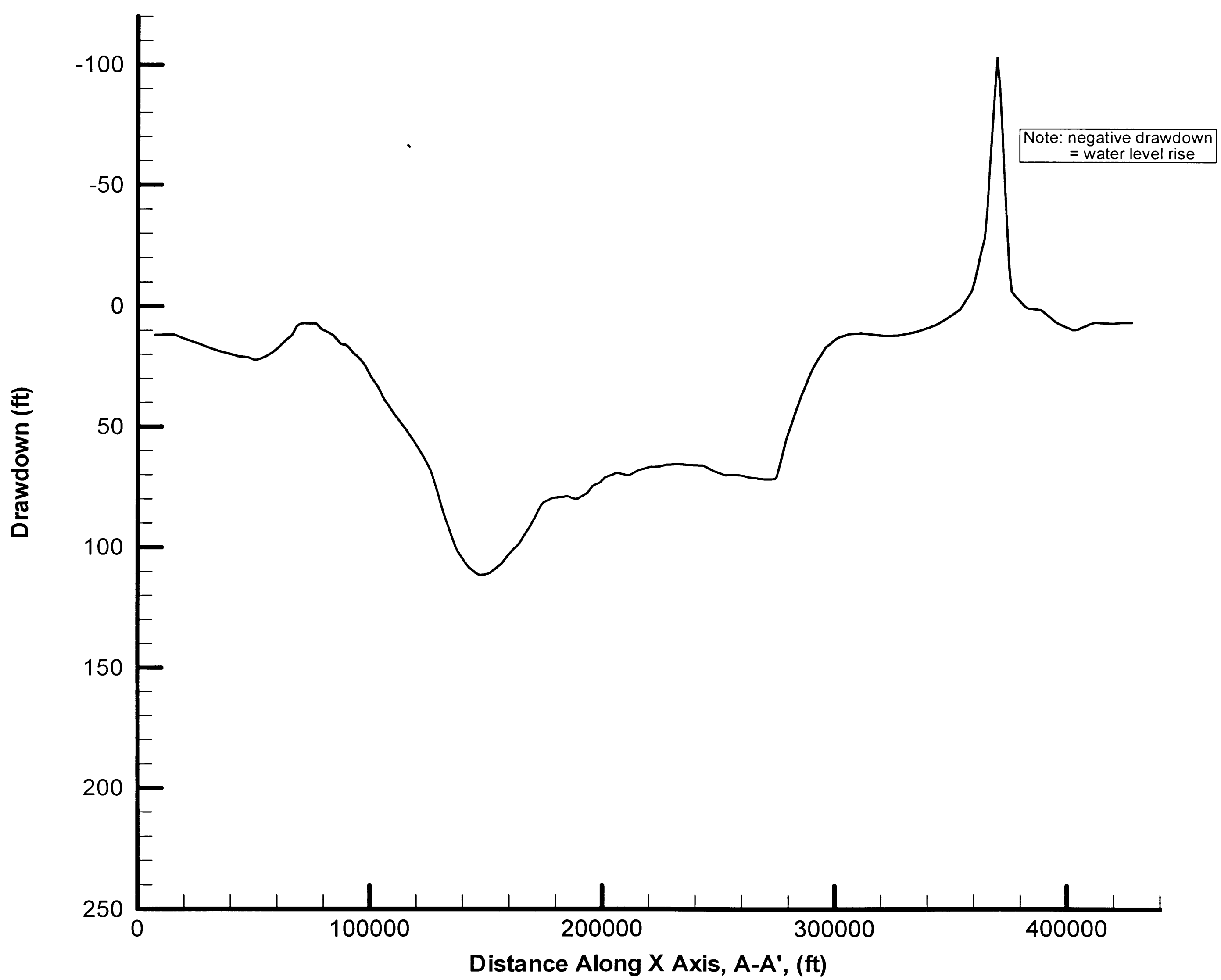


Figure A-5

Profile B - B', Drawdown in Simsboro Aquifer (ft) - 2040
HDR Model, 55,000 ac-ft/yr Scenario

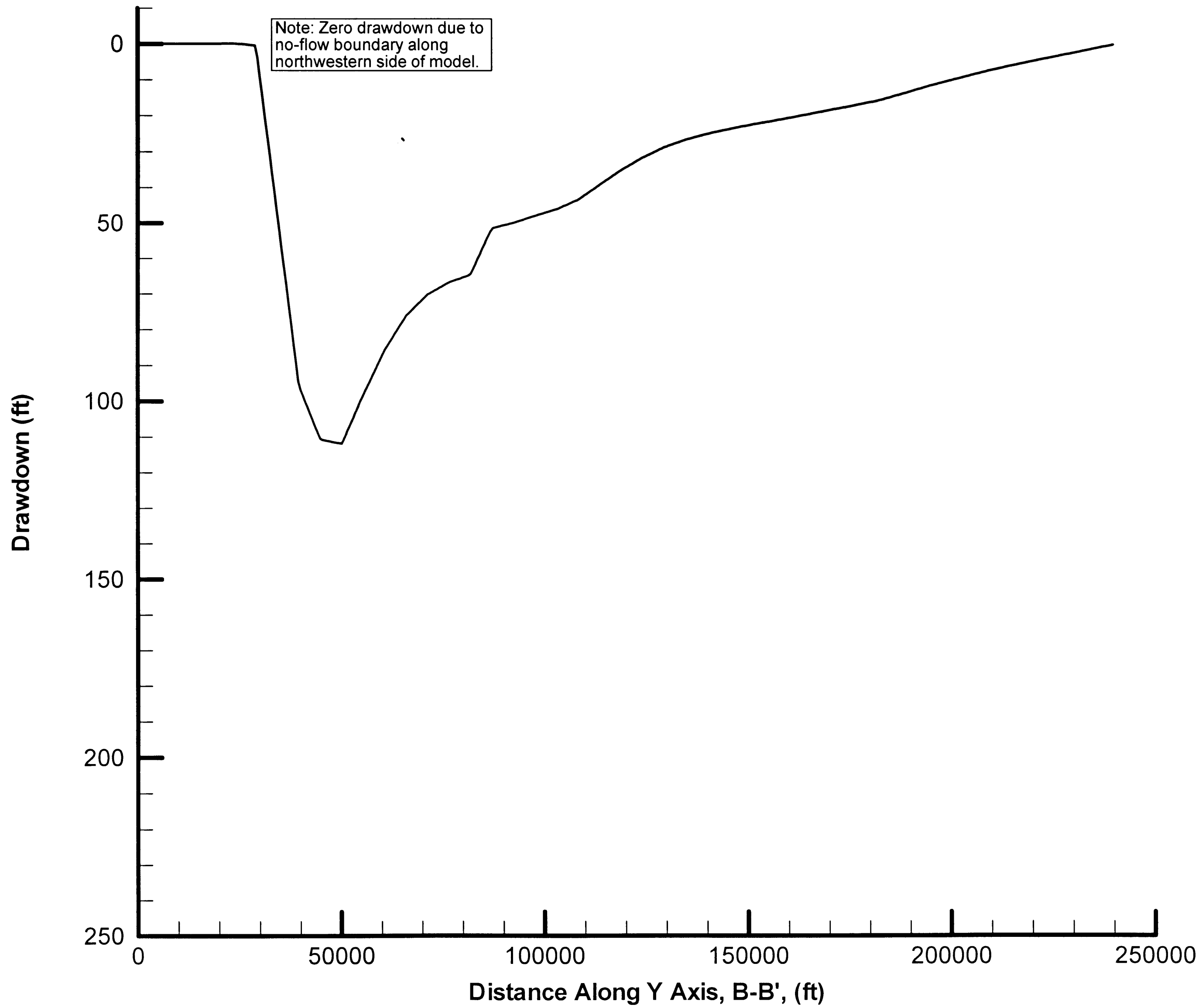


Figure A-6

Appendix B

Recharge Rates Used in HDR Model

The HDR model is a modification of a model produced by Dutton (Dutton, 1999). The major modification introduced by HDR was the method of applying recharge. Dutton applied recharge at a constant rate of zero to four inches per year, depending on location. HDR applied recharge using constant head cells. This results in recharge varying in time as well as location.

HDR did not report the amount of recharge applied in their model. When asked to provide this information, HDR refused[17].

For this evaluation, recharge rates for selected cells in the HDR model were calculated using the method described in the MODFLOW documentation[18]. As shown in table B1, recharge rates applied to some cells are unrealistic. In at least one case the recharge rate exceeds the average annual rainfall of 36 inches by a factor of more than eight.

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[17] Personal communication with Larry Land, 12 July 2000. Mr. Land also refused to release model calibration data and refused to identify the well locations (i.e., the subset of Texas Water Development Board and Alcoa data) that HDR used to calibrate the model.
[18] M[c]Donald and Harbaugh, 1988, pages 5-11 – 5-19.

Table B1
HDR Model Recharge Rates
Calculated for Selected Cells in the Simsboro Aquifer
55,000 ac-ft/yr scenario

Model Cell (layer, row, column)	Recharge Rate Applied by Model in Year 2040 (in/yr)	Remarks
(4,6,18)	24.6	Constant head cell immediately above well in Simsboro Aquifer. Simulated pumpage from well = 32,979 ft^3/day (276 ac-ft/yr).
(4,6,21)	17.7	Constant head cell immediately above well in Simsboro Aquifer. Simulated pumpage from well = 142,881 ft^3/day (1197 ac-ft/yr).
(4,6,26)	2.0	
(4,7,28)	3.0	
(4,7,40)	29.6	
(4,8,40)	289.7	Constant head cell immediately above well in Simsboro Aquifer. Simulated pumpage from well = 61,660 ft^3/yr (517 ac-ft/yr).
(4,8,44)	22.7	
(4,8,47)	23.7	Constant head cell immediately above well in Simsboro Aquifer. Simulated pumpage from well = 583 ft^3/yr (4.9 ac-ft/yr).
(4,9,11)	-109.4	Negative sign indicates water from Simsboro Aquifer recharging Calvert Bluff.

Sample Calculation of Recharge Rate

L = vertical leakance[19] assigned to cell (3,8,44) = 2.25E-3/day

h_1 = constant head in cell (3,8,44) (Calvert Bluff) = 309.8 ft.

h_2 = head in cell (4,8,44) (Simsboro) at end of pumping period 12, time step 20 (year 2040) = 307.5 ft.

Recharge rate[20] = L (h_1 – h_2) = 2.25E-3/day (309.8 ft - 307.5 ft) = 5.175E-3 ft/day = 22.7 in/yr.

[19] Vertical leakance is defined as the vertical hydraulic conductivity divided by the distance between layers (midpoints of layers). See M^c^Donald and Harbaugh, 1988, pages 5-12 through 5-15. Vertical leakances assigned by HDR.
[20] See M^c^Donald and Harbaugh, 1988, page 5-19. Note: vertical leakance is also defined as vertical conductance divided by cell area (M^c^Donald and Harbaugh, 1988, pages 5-11 – 5-12).

Appendix C

Underestimation of historic drawdowns

Figures C-1 through C-3 compare measured (historic) drawdowns in the Simsboro Aquifer to drawdowns estimated by the HDR model. The historic drawdowns represent changes in static water levels[21]. The numbers in parentheses represent cell locations (layer, row, column) in the HDR model.

[21] Alcoa, 2000, Appendices A and B.

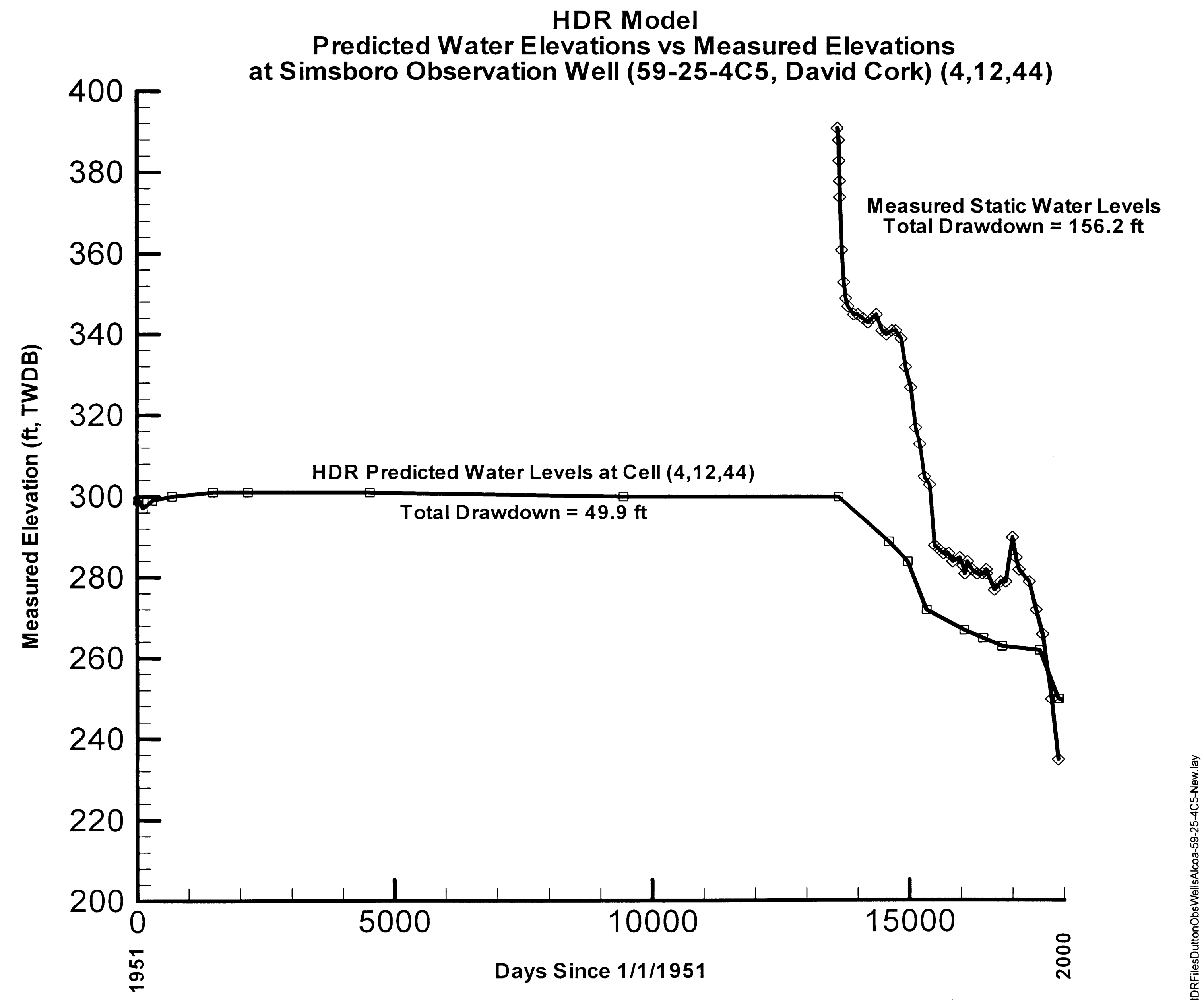
HDR Model
Predicted Water Elevations vs Measured Elevations
at Simsboro Observation Well (59-25-4C5, David Cork) (4,12,44)
Measured Static Water Levels
Total Drawdown = 156.2 ft
HDR Predicted Water Levels at Cell (4,12,44)
Total Drawdown = 49.9 ft
Measured Elevation (ft, TWDB)
400
380
360
340
320
300
280
260
240
220
200
0
5000
10000
15000
1951
2000
Days Since 1/1/1951
C:HDRFilesDuttonObsWellsAlcoa-59-25-4C5-New.lay

Figure C-1

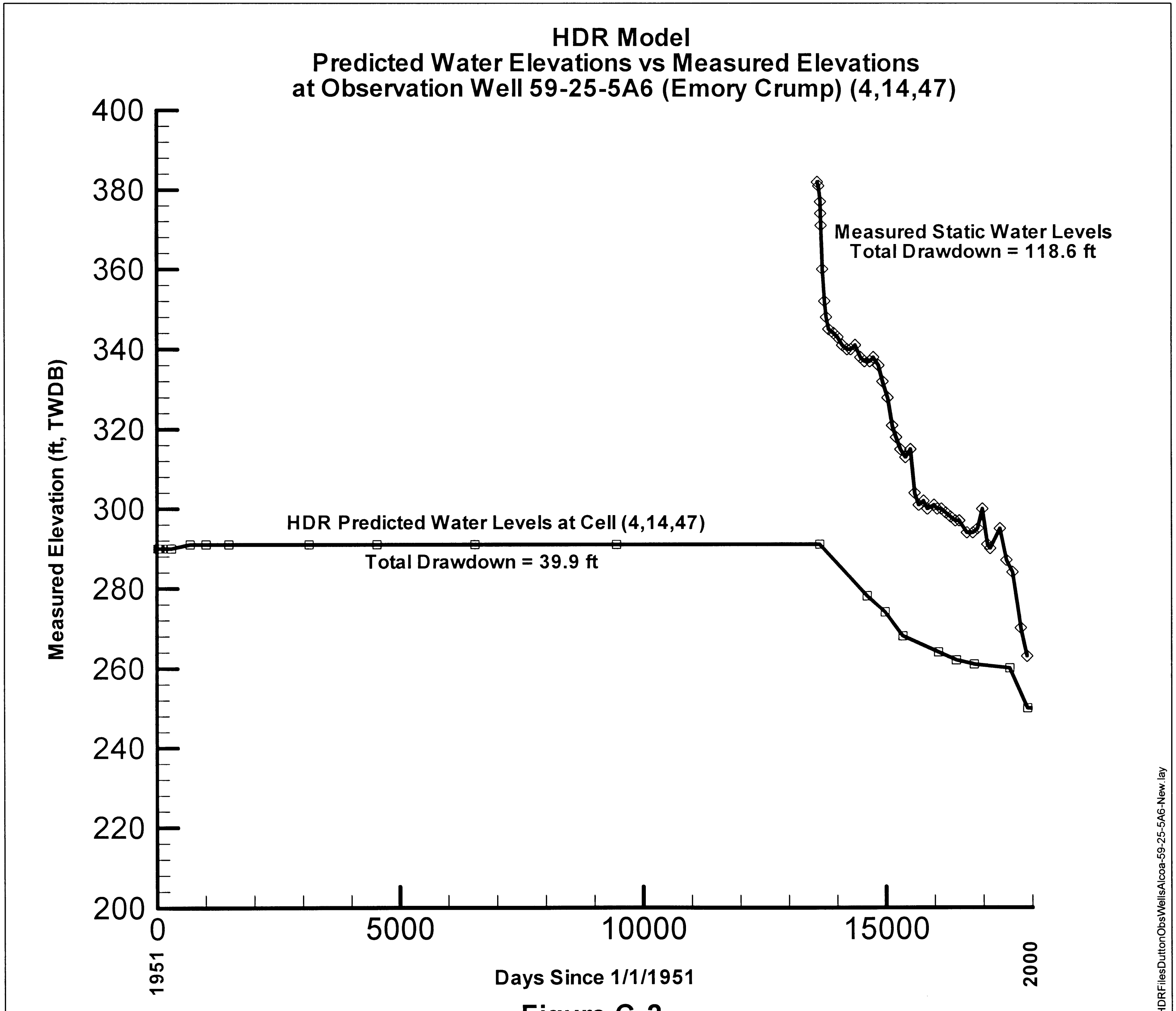
HDR Model
Predicted Water Elevations vs Measured Elevations
at Observation Well 59-25-5A6 (Emory Crump) (4,14,47)
Measured Static Water Levels
Total Drawdown = 118.6 ft
HDR Predicted Water Levels at Cell (4,14,47)
Total Drawdown = 39.9 ft
Measured Elevation (ft, TWDB)
400
380
360
340
320
300
280
260
240
220
200
0
5000
10000
15000
1951
2000
Days Since 1/1/1951
C:HDRFilesDuttonObsWellsAlcoa-59-25-5A6-New.lay

Figure C-2

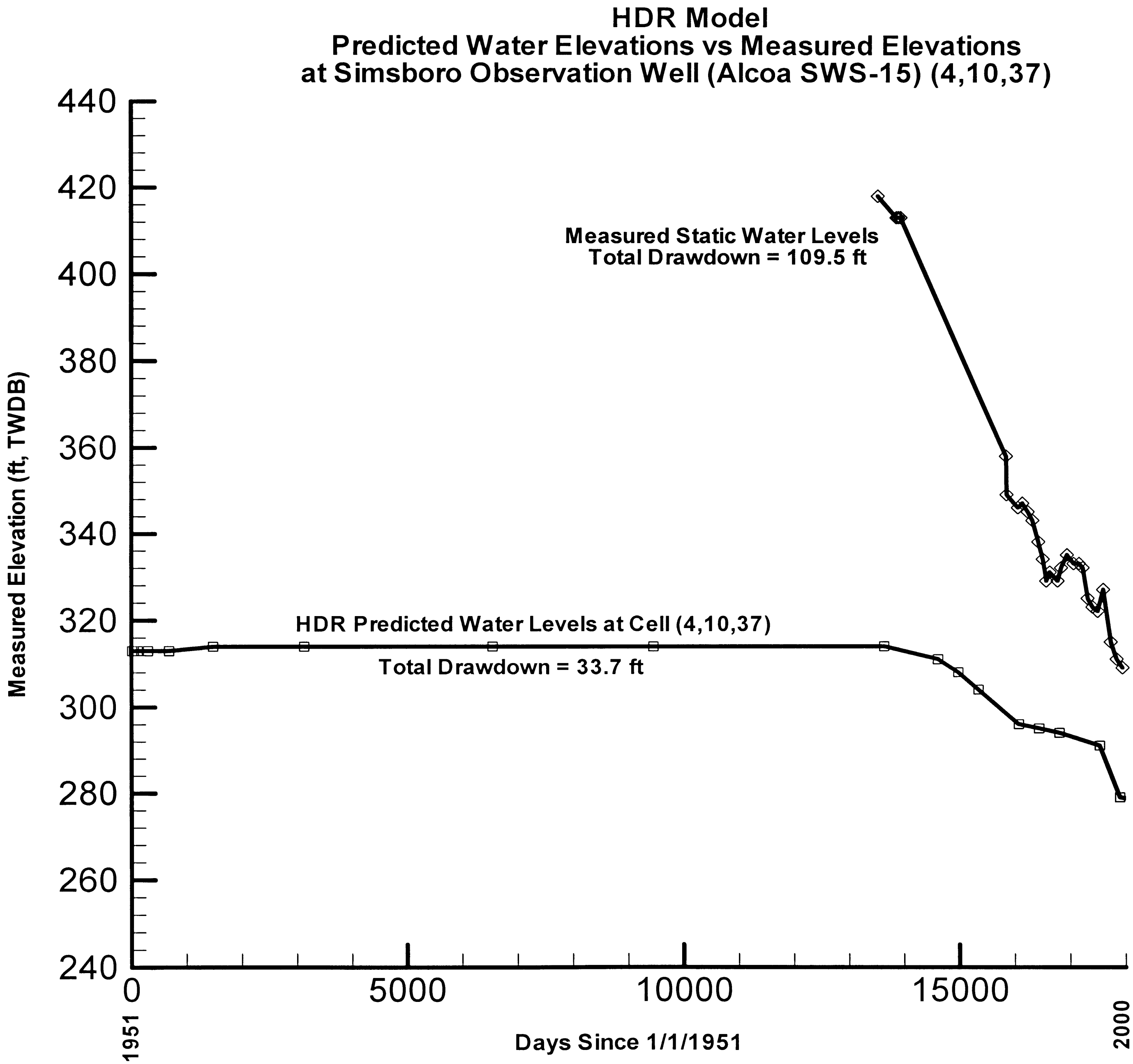

Figure C-3

C:HDRFilesDuttonObsWellsAlcoa-SS-15-New.lay

Appendix D

Rising water levels in Carrizo Aquifer

Figure D-1 shows the increases in Carrizo water levels predicted by the HDR model from 2000 to 2040. Figure D-2 shows the predicted increase in pumpage from the Carrizo Aquifer during this period. The pumpage data was taken from an HDR model input file.

In figure D-1 the X axis corresponds to the southeast boundary of the study area shown in figure 1. The Y axis corresponds to the southwest boundary of the study area.

HDR Model Prediction
Water Level Rises in Carrizo Aquifer
Years 2000 - 2040

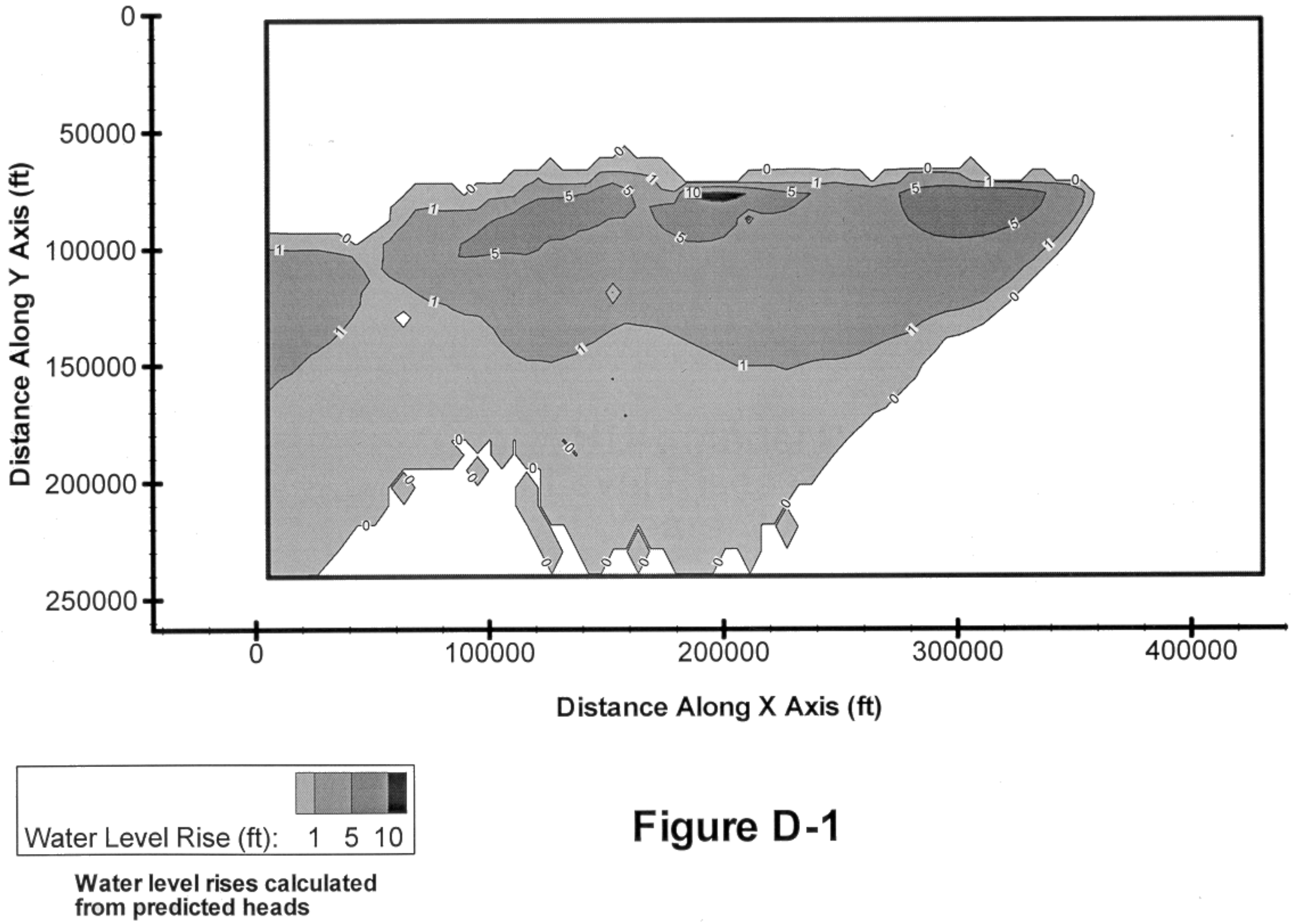

Figure D-1

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Pumpage From Carrizo Aquifer, 2000 - 2040
HDR Model, 55,000 ac-ft/yr Scenario

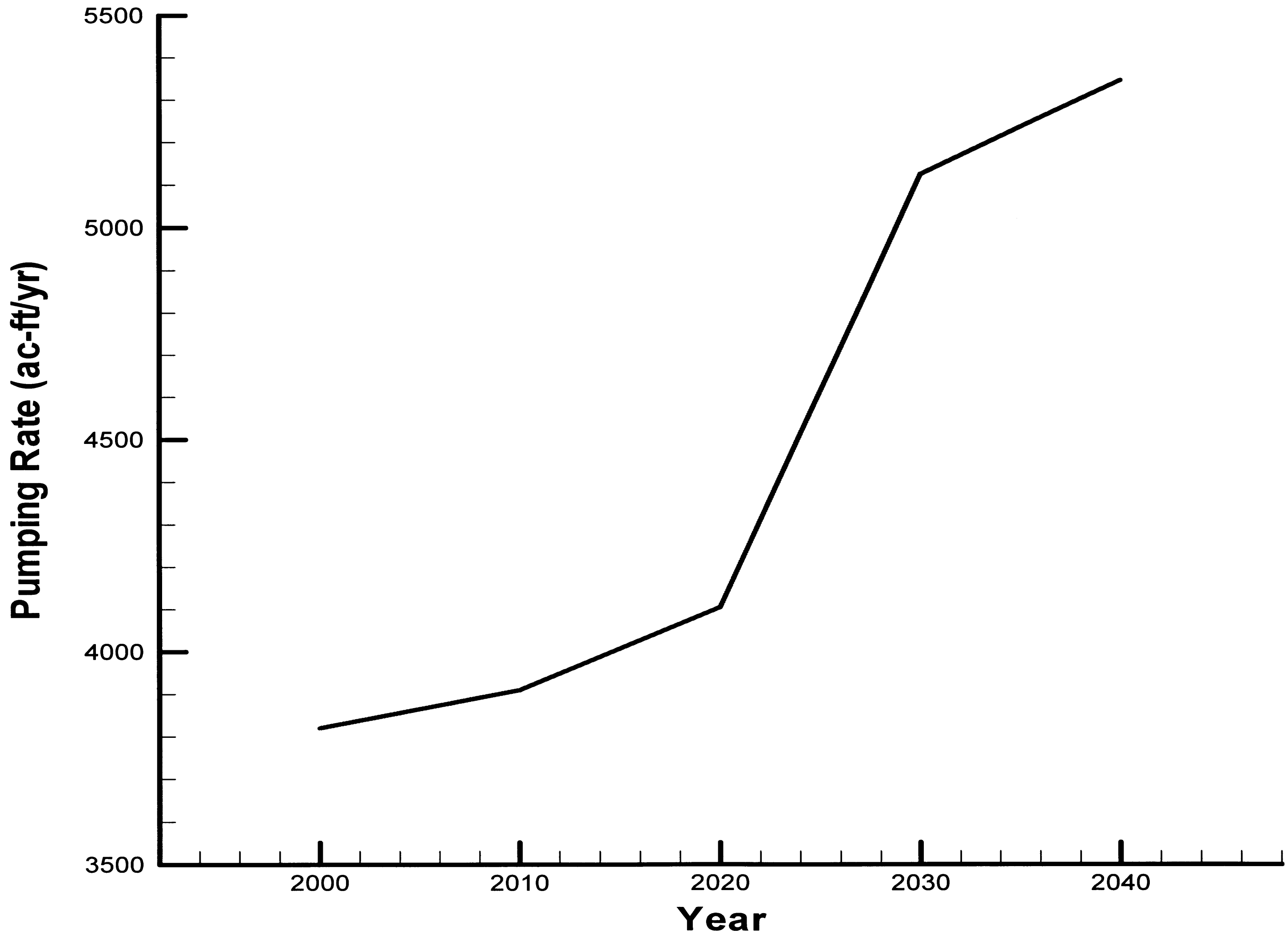

Figure D-2

Attachment 1
SAWS's comments and related correspondence

San Antonio Water System

July 19, 2001

Mr. George Rice
414 East French Place
San Antonio, TX 78212

Dear Mr. Rice:

I am in receipt of your letter of June 29, 2001 and report addressing the HDR model for the Carrizo-Wilcox aquifer located in Bastrop and Lee Counties. Thank you for your interest and I appreciate the opportunity to provide SAWS comments on the report. Continuing refinement of hydrological knowledge of the project area is essential to the completion of a successful water supply project. Attached are SAWS comments regarding the report. Please provide me with the name of the group commissioning your report so that I might have the opportunity to meet with them.

Sincerely,

Eugene E. Habiger
General, USAF (Ret.)
President/Chief Executive Officer

Cc: Susan Butler

Attachment

Evaluation of SAWS/HDR Modeling of the Carrizo-Wilcox Aquifer in Lee, Bastrop, and Miliam Counties

SAWS Comments

The following comments address the areas identified as "problems with the HDR Model".

Rising Water Levels in the Carrizo Aquifer

- Water level gains initially shown in the model were a result of starting head elevations and land surface elevations that were initially set much too low near the updip limit of layer 1. Changes were applied and the model was rerun. The result was that water levels declined slightly (approximately 2 feet).

- Alcoa currently pumps approximately 30,000 acre feet per year with drawdown in the well field ranging between 75 – 150 feet. This is concentrated within the boundary of the Sandow Mine property and near the open mine. Pumping for SAWS Simsboro project will be spread over a greater area (~28 miles in length) and is therefore less concentrated. This is expected to result in much less drawdown.

Underestimation of Historic Drawdowns

- The calibration period for the HDR model was from 1950 to 1997. Based on Dec 1997 water level measurements by ALCOA, the total drawdowns were 109 ft, 92 ft, and 85 ft instead of the reported 156 ft, 118 ft, and 109 ft for the historic record of the three referenced wells. In the Alcoa network of about 35 monitoring wells, it was not determined if these are representative wells or not, nor if the selected cells are the most appropriate ones for a comparison.

- The BEG and HDR models were designed to represent the regional system with one square mile cells and for long-term projections. The regional approach causes local details such as location of pumping wells and local aquifer features to be generalized. Likewise, the long-term simulations lead the modelers to smooth variable pumping rates over several years. As a result, the emphasis for calibration is not on individual wells located in areas where conditions are highly variable, but on wells with long-term data that are expected to reflect regional characteristics.

Unrealistic Recharge Rates

- Although previous researchers have estimated recharge to range from 1-4 in/yr, the Bureau of Economic Geology model utilized an average effective recharge rate of 1 inch per year (BEG report, page 17). Communication with Dr. Dutton has indicated that this is very conservative recharge component and actual recharge may be higher. To-date, little scientific research has been conducted to quantify recharge.

- The concept of recharge utilized by HDR in the modeling of the Carrizo-Wilcox Aquifer system in the area of the Alcoa-CPS properties is an accepted method. Increased recharge associated with water level decline is documented by several United States Geological Survey (USGS) publications.
    - Ryder & Ardis, 1991, USGS Open-file Report 91-64
    - US Geological Survey Circular 1186

- The basic Groundwater flow equation (Darcy's Law) calculates groundwater flow to be directly proportional to the hydraulic gradient. Pumping in the deeper zones of the aquifer lowers water levels; thus, increases the hydraulic gradient and allows for groundwater to flow into the deeper zones.

- The overall average effective recharge applied to the HDR model (focusing on the Alcoa-CPS areas) is approximately 6.51 inches per year utilizing a constant head boundary in the overlying layer of the model.

- The TWDB Groundwater Assessment Modeling (GAM) request for proposals specifically requires the application of the concept of rejected recharge, thus supporting the concept of increasing recharge with the decline in water levels.

- It can reasonably be expected that the Carrizo-Wilcox will receive recharge from both the outcrop area and drainage features that cross the project area. The concept is similar to the contributing zone of the Edwards aquifer.

- The GAM modeling will address recharge rates of the Central Carrizo-Wilcox area and provide additional scientific data and analysis.

Drawdowns Intercept Artificial Boundaries

- Selection of boundaries is an issue that was previously presented in the recommendations section of the BEG report (page 40). Dr. Dutton stated that boundaries for the model produced by the BEG required adjustment.

- As stated by HDR, the model produced for the Alcoa/CPS property was a modification of the BEG model, the boundaries were in the same location; therefore, like the BEG model, water level decline may be overstated in some areas and understated in other areas.

- Selection of boundaries is addressed in the current GAM modeling effort.

August 4, 2001

Eugene Habiger
President/CEO
San Antonio Water System
1001 E. Market Street
P.O. Box 2449
San Antonio, TX 78298-2449

Dear Mr. Habiger,

Thank you for your comments on my draft report: *Evaluation of SAWS/HDR Modeling of the Carrizo-Wilcox Aquifer in Lee, Bastrop, and Milam Counties.* In your letter you said you would like to meet with the group that commissioned it. No one commissioned the report. However, I work with several citizen's groups that are interested in this issue. I'm sure they would be willing to meet with you.

Bastrop County Environmental Network
P.O. Box 1069, Bastrop TX 78602
Ron Giles, (512) 360-4043, gilesron@aol.com

Friends of the Lost Pines State Parks
P.O. Box 1714, Bastrop, TX 78602
Jon Pollard, (512) 321-3740

Neighbors for Neighbors
P.O. Box 661, Elgin, TX 78621
President: Billie Woods, (512) 281-2983, kokopele@totalaccess.net
Water Issues: Michele Gangnes, (512) 281-5352, mggangnes@aol.com

In addition, I would be happy to meet with you, your staff, and representatives of HDR to answer questions about the evaluation. Also, your first comment states "Changes were applied and the model was rerun." May I have copies of the changed input and output files?

Sincerely,

George Rice
414 East French Place
San Antonio, TX 78212
tel/fax: (210) 737-6180
jorje44@yahoo.com

San Antonio Water System

October 11, 2001

Mr. George Rice
414 East French Place
San Antonio, Texas 78212

Dear Mr. Rice:

Similar to the procedure outlined in previous correspondence regarding water model files that you have requested, I feel an explanation of the availability of contractor work products at the San Antonio Water System (SAWS) will help clear up the associated issues. When contractors perform one-time work for the San Antonio Water System, all files are generally copied for SAWS. However, when a contractor has been contracted to perform on-going work and especially on the same project, then files are retained at the contractor's office. This provides the contractor the opportunity to update the model as additional information is generated and to provide additional model runs as they are required. As you are aware, water from the Simsboro project will not be produced until the 2015 timeframe; therefore, it can be expected that the model will be updated numerous times as new information becomes available.

In your letter dated August 4, 2001, you request the changed input and output files. Since SAWS does not currently need to have these files in our possession, this is an extra cost that we would not normally incur. If you would like these files downloaded for your use, the $455.00 charge is what SAWS presently would have to pay for them. In the future, when all modeling activity has been completed for this project, SAWS will request files be provided to us in electronic format and will have them available for distribution to the general public; however, this data may not be available for several years (estimated January 2004).

If you should have any further questions or comments, please contact the SAWS Resource Development Department at (210) 704-7346.

Sincerely,

Eugene E. Habiger
General, USAF (Ret.)
President/CEO

cc: Susan Butler, Director of Resource Development
Kevin Morrison, Resource Development