5.0 MODEL CALIBRATION AND SENSITIVITY ANALYSIS

5.1 Flow Model Calibration

Model calibration is achieved when the model reasonably simulates the interpreted groundwater flow conditions within the geologic units of interest using inputs that are within the range of measured or estimated values. The locations of pre-mining monitoring wells used in calibrating the steady-state model are shown in Figure 5-1. For transient-state calibration, modeled water levels were compared with water level monitoring data from the Gillette Area Groundwater Monitoring Organization (GAGMO) and BLM monitoring wells. In addition, modeled annual CBM water production rates were compared with reported annual water production for the sub-watersheds between 1987 and 2000. Calibration was performed iteratively between steady-state and transient-state model runs. All water level monitoring data were entered into the model so that this comparison could be made.

The following criteria were used in this study to calibrate the flow model:

1. Match actual steady-state groundwater elevations (“heads”) for pre-mining (generally prior to 1975) with the heads predicted by the model.

2. Evaluate the overall global water balance to assess whether the model reasonably predicts flow into and out of the system by comparison with estimated groundwater discharges to surface drainages.

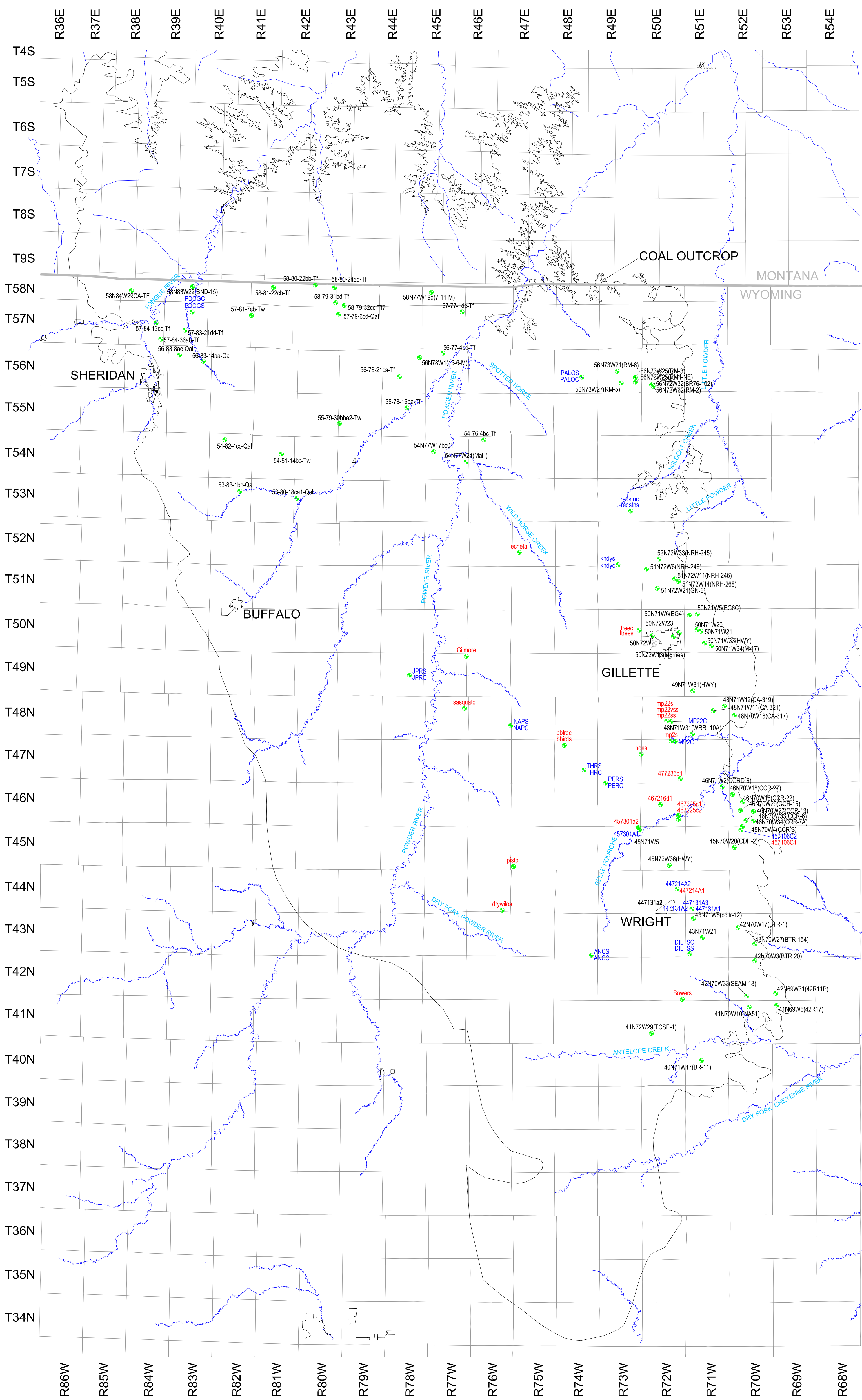
3. Match transient-state groundwater elevations (“heads”) for post-mining and post-CBM development with the heads predicted by the model. Monitoring well data from GAGMO and BLM monitoring wells were used for this calibration. Interpreted potentiometric maps (areal comparison at different times) and individual monitoring well hydrographs (temporal comparison at different locations) were compared.

4. Match year-by-year historical CBM production in various selected areas with water production predicted by the model.

5.1.1 Steady-State Calibration

Pre-mining potentiometric data are sparse. Available data are summarized in Table 2-2. Figure 2-3 shows the interpreted pre-mining (assumed steady state) potentiometric surface in the upper Fort Union Formation. Steady-state model runs were conducted and compared with actual water levels for pre-mining conditions. Steady-state calibration was conducted by varying model input parameters, primarily recharge rates and hydraulic conductivity. This calibration was iterative with the transient calibration discussed in Section 5.1.2.

Figure 5-2 shows the model-predicted steady state potentiometric surface for the upper Fort Union Formation. The comparison of actual observed heads to model-predicted heads at the pre-mining calibration points is shown in Table 5-1 and is graphically illustrated in Figure 5-3. Points above the line in Figure 5-3 represent heads over-predicted by the model.



LEGEND

- Rivers
- Towns
- Calibration Wells
- 56-78-21ca-Tf Steady State Calibration Well
- 45106C1 Transient Calibration Well
- drywilos Both Transient and Steady State Calibration Well

Note: Steady state calibration wells consist of wells from the Sheridan County well records (1966), Daddow's potentiometric-surface map of the Wyodak-Anderson coal (1986), and existing BLM wells. Transient calibration wells are BLM wells only.

N

0 7.5 15 30 Miles

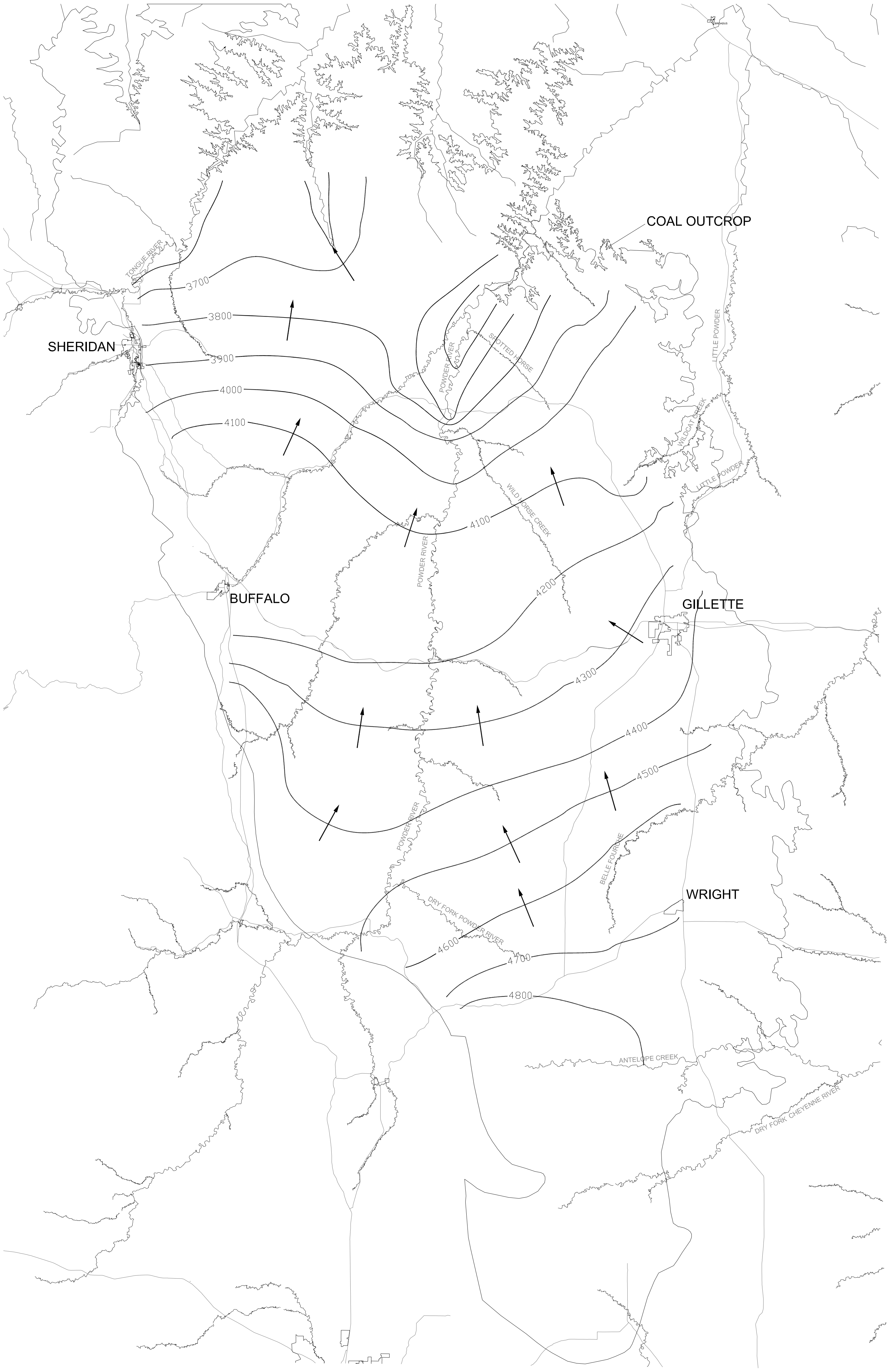
POWDER RIVER BASIN OIL & GAS PROJECT FEIS

TECHNICAL REPORT GROUNDWATER MODELING

FIGURE 5-1
LOCATION OF CALIBRATION WELLS

MODEL RUN: From 1999-2200 (08-26-02)	
Date: 09/04/02	Drawing File: Figure 5-1.dwg
Scale: As Noted	Drawn By: ETC

Figure 5-1 continued (11x17)



LEGEND

- Rivers
- Roads
- Towns
- Potentiometric Contour (ft)

N

0 7.5 15 30 Miles

POWDER RIVER BASIN
OIL & GAS PROJECT FEIS

TECHNICAL REPORT GROUNDWATER MODELING

FIGURE 5-2
MODELED PRE-MINING
POTENTIOMETRIC HEADS
(STEADY STATE)

MODEL RUN: From 1999-2200 (08-26-02)

Date: 09/04/02	Drawing File: Figure 5-2.dwg
Scale: As Noted	Drawn By: ETC

Figure 5-2 continued (11x17)

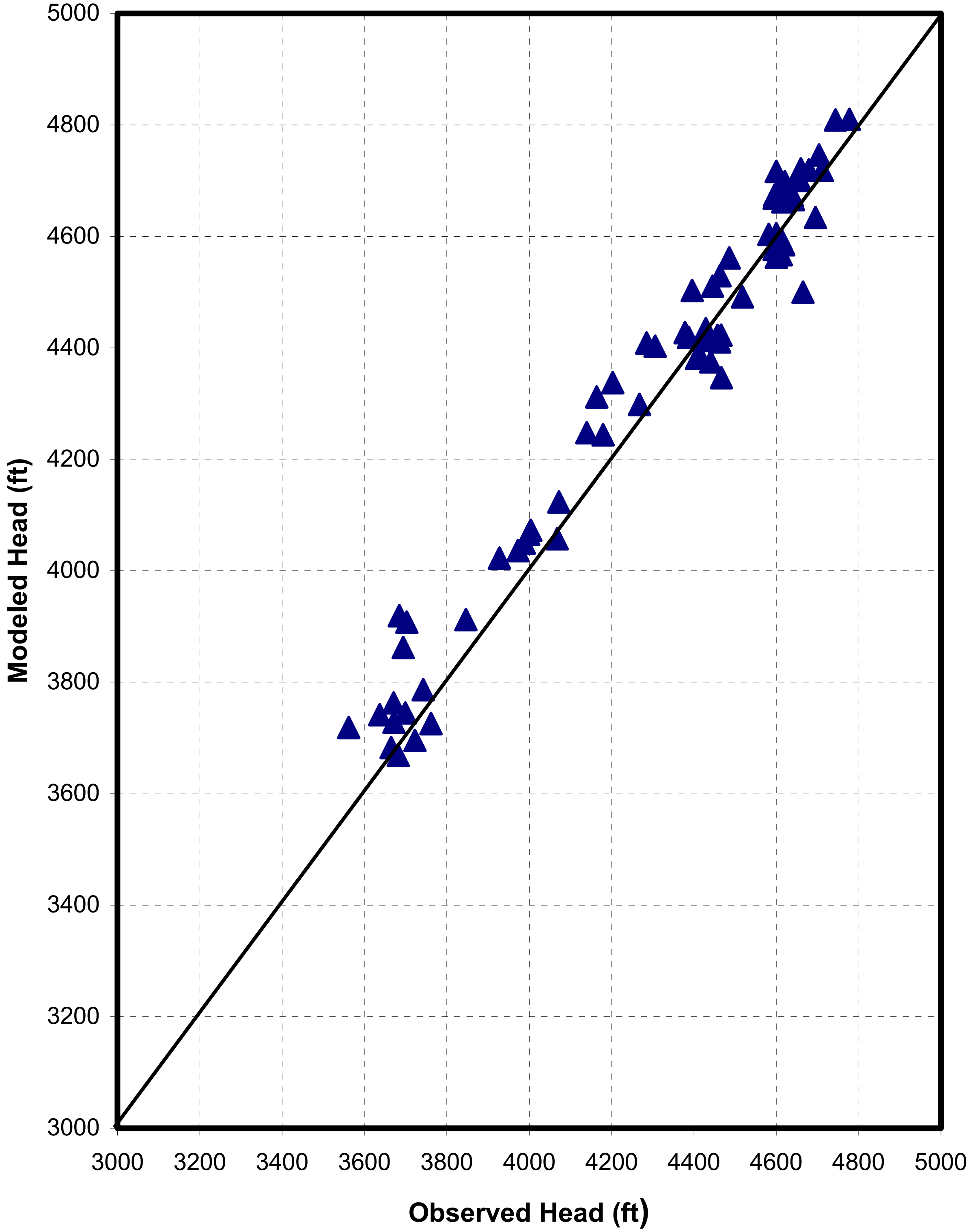
Table 5-1
Results of Steady-State Calibration for Observation Wells

Observation Well Name	Source of Data	Water Level Date	Observed Head (ft)	Modeled Head (ft)	Residual (observed -modeled)
40N71W17(BR-11)	Daddow	Oct-81	4695.0	4634.0	60.9
41N69W6(42R17)	Daddow	Dec-80	4778.0	4810.0	-32.0
41N70W10(NA51)	Daddow	Dec-80	4642.0	4665.9	-23.9
41N72W29(TCSE-1)	Daddow	Nov-82	4658.0	4700.4	-42.4
42N69W31(42R11P)	Daddow	Dec-80	4744.0	4808.9	-64.9
42N70W17(BTR-1)	Daddow	NA	4608.0	4688.9	-80.9
42N70W3(BTR-20)	Daddow	NA	4653.0	4705.6	-52.6
42N70W33(SEAM-18)	Daddow	Aug-78	4595.0	4668.6	-73.6
43N70W27(BTR-154)	Daddow	Oct-73	4621.0	4697.9	-77.0
43N71W21	Daddow	Jul-79	4605.0	4672.0	-67.0
43N71W5(CDLTR-12)	Daddow	Aug-78	4616.0	4662.0	-46.0
447131a1	BLM	NA	4679.3	4719.3	-40.0
447214a1	BLM	1998	4594.75	4634.75	-40.0
457106c1	BLM	1997	4576.87	4585.93	-9.1
457301a1	BLM	1997	4606.23	4550.31	55.9
457301a2	BLM	NA	4594.6	4576.9	17.7
45N70W20(CDH-2)	Daddow	Aug-78	4639.0	4673.4	-34.4
45N70W4(CCR-3)	Daddow	NA	4600.0	4716.3	-116.4
45N71W5	Daddow	May-77	4612.0	4594.4	17.6
45N72W36(HWY)	Daddow	NA	4600.0	4604.8	-4.9
467216d1	BLM	NA	4463.8	4529.5	-65.7
467225c1	BLM	1996	4600.2	4562.9	37.3
467225c2	BLM	NA	4618.0	4585.3	32.7
467236b1	BLM	NA	4612.6	4567.2	45.4
46N70W16(CCR-22)	Daddow	NA	4628.0	4667.9	-40.0
46N70W18(CCR-27)	Daddow	NA	4582.0	4603.6	-21.6
46N70W27(CCR-13)	Daddow	NA	4712.0	4718.3	-6.3
46N70W29(CCR-15)	Daddow	NA	4596.0	4673.7	-77.7
46N70W33(CCR-6)	Daddow	NA	4660.0	4720.9	-60.9
46N70W34(CCR-7A)	Daddow	NA	4704.0	4745.9	-42.0
46N71W2(CORD-9)	Daddow	NA	4486.0	4561.3	-75.3
477119c1	BLM	1995	4405.0	4502.8	-97.8
477236b1	BLM	1995	4445.2	4510.7	-65.6
48N70W18(CA-317)	Daddow	May-76	4665.0	4499.5	165.4
48N71W11(CA-321)	Daddow	May-76	4466.0	4422.7	43.3
48N71W12(CA-319)	Daddow	May-76	4518.0	4491.5	26.5
48N71W31(WRRI-10A)	Daddow	Nov-79	4457.0	4422.3	34.7
49N71W31(HWY)	Daddow	Dec-77	4463.0	4410.7	52.3
50N71W20	Daddow	Mar-77	4418.0	4413.6	4.4
50N71W21	Daddow	May-77	4387.0	4418.9	-32.0
50N71W33(HWY)	Daddow	Jun-74	4379.0	4427.2	-48.2
50N71W34(M-17)	Daddow	Aug-78	4429.0	4434.7	-5.7
50N71W5(EG6C)	Daddow	Oct-76	4285.0	4408.7	-123.7
50N71W6(EG4)	Daddow	Oct-76	4306.0	4403.2	-97.2
50N72W13(Morries)	Daddow	Jun-78	4414.0	4385.5	28.5
50N72W20	Daddow	NA	4467.0	4346.4	120.6
50N72W23	Daddow	NA	4441.0	4374.9	66.1

Table 5-1 (Continued)
Results of Steady-State Calibration for Observation Wells

Observation Well Name	Source of Data	Water Level Date	Observed Head (ft)	Modeled Head (ft)	Residual (observed -modeled)
51N72W14(NRH-268)	Daddow	NA	4203.0	4337.9	-134.9
51N72W21(GN-6)	Daddow	Feb-77	4268.0	4298.4	-30.4
51N72W6(NRH-246)	Daddow	NA	4140.0	4247.8	-107.8
52N72W33(NRH-245)	Daddow	NA	4180.0	4244.2	-64.3
53-80-18ca1-Qal	Sheridan	NA	4072.2	4123.2	-51.0
53-83-1bc-Qal	Sheridan	NA	4406.5	4381.1	25.4
54-76-4bc-Tf	Sheridan	NA	3846.8	3912.4	-65.6
54N77W17bc01	BLM	Aug-84	3694.0	3862.2	-168.2
54N77W24(Malli)	Daddow	Feb-79	3703.0	3907.7	-204.7
55-78-15ba-Tf	Sheridan	NA	3699.1	3745.1	-46.0
56-77-4bd-Tf	Sheridan	NA	3682.1	3668.7	13.3
56-78-21ca-Tf	Sheridan	NA	3742.1	3787.0	-44.9
56-83-14aa-Qal	Sheridan	NA	3664.7	3682.7	-18.0
56N72W32(BR76-102)	Daddow	Sep-76	4004.0	4072.8	-68.9
56N72W32(RM-2)	Daddow	Aug-75	3999.0	4065.9	-66.9
56N73W21(RM-6)	Daddow	Aug-75	3928.0	4022.5	-94.6
56N73W25(RM-3)	Daddow	Nov-79	3988.0	4049.7	-61.7
56N73W25(RM4-NE)	Daddow	May-76	4068.0	4057.4	10.6
56N73W27(RM-5)	Daddow	Sep-75	3973.0	4036.1	-63.1
56N78W1(15-6-M)	Daddow	Aug-84	3672.0	3728.2	-56.2
57-77-1dc-Tf	Sheridan	NA	3670.9	3762.8	-91.9
57-79-6cd-Qal	Sheridan	NA	3761.5	3726.0	35.4
57-81-7cb-Tw	Sheridan	NA	3637.1	3742.0	-104.9
57-84-13cc-Tf	Sheridan	NA	3562.0	3718.8	-156.8
58-79-31bd-Tf	Sheridan	NA	3722.4	3695.5	26.9
58-79-32cc-Tf?	Sheridan	NA	3716.9	3705.3	11.6
58-80-24ad-Tf	Sheridan	NA	3666.0	3665.4	0.6
58-81-22cb-Tf	Sheridan	NA	3858.6	3783.7	74.9
58N77W19d(7-11-M)	BLM	Aug-84	3802.0	3746.0	55.9
58N83W22(BND-15)	Daddow	Apr-84	3475.0	3698.2	-223.2
bbirdc	BLM	NA	4412.3	4375.3	37.0
bbirds	BLM	NA	4524.6	4452.7	72.0
Bowers	BLM	NA	4567.9	4670.0	-102.2
diltsc	BLM	NA	4590.1	4671.2	-81.0
diltss	BLM	NA	4810.7	4700.0	110.7
drywilos	BLM	NA	4852.7	4774.4	78.3
Echeta	BLM	Apr-84	4020.9	4157.7	-136.8
Gilmore	BLM	NA	4166.8	4191.5	-24.7
hoes	BLM	NA	4637.3	4580.8	56.6
ltreec	BLM	NA	4308.3	4310.6	-2.3
ltrees	BLM	NA	4445.4	4392.3	53.0
mp22s	BLM	NA	4474.3	4478.0	-3.8
mp22ss	BLM	NA	4520.9	4511.3	9.5
mp22vss	BLM	NA	4539.1	4541.3	-2.2
mp2s	BLM	NA	4490.6	4497.8	-7.2
Pistol	BLM	1997	4653.3	4535.1	118.2
Sasquatc	BLM	1997	4244.8	4261.7	-16.9

Figure 5-3 Modeled vs. Observed Heads for Pre-mining Calibration Wells



Overall, the calibrated model simulates pre-mining groundwater flow conditions fairly well, with about 75 percent of the modeled heads within plus or minus 70 feet of observed heads. The root-mean-square of all the model calibration points was 75 feet. Modeled and actual water levels may differ in a few areas by as much as plus or minus 200 feet. However, the pre-mining data from these wells are acknowledged to be questionable. The level of accuracy for calibration is believed to be reasonable in light of the regional nature of the model, with a grid spacing of one–half mile.

Pre-mining potentiometric heads predicted by the model in the coal will tend to be higher than actual (observed) heads because the model assumes 1975 as the pre-mining condition, while many of the observed heads assume 1980 as the pre-mining base year. Mining that occurred before 1980 presumably caused some level of drawdown, particularly in the coal, in the vicinity of active mines. Gradients simulated by the model were similar to observed gradients.

5.1.2 Steady-State Calibration to Powder River Baseflows

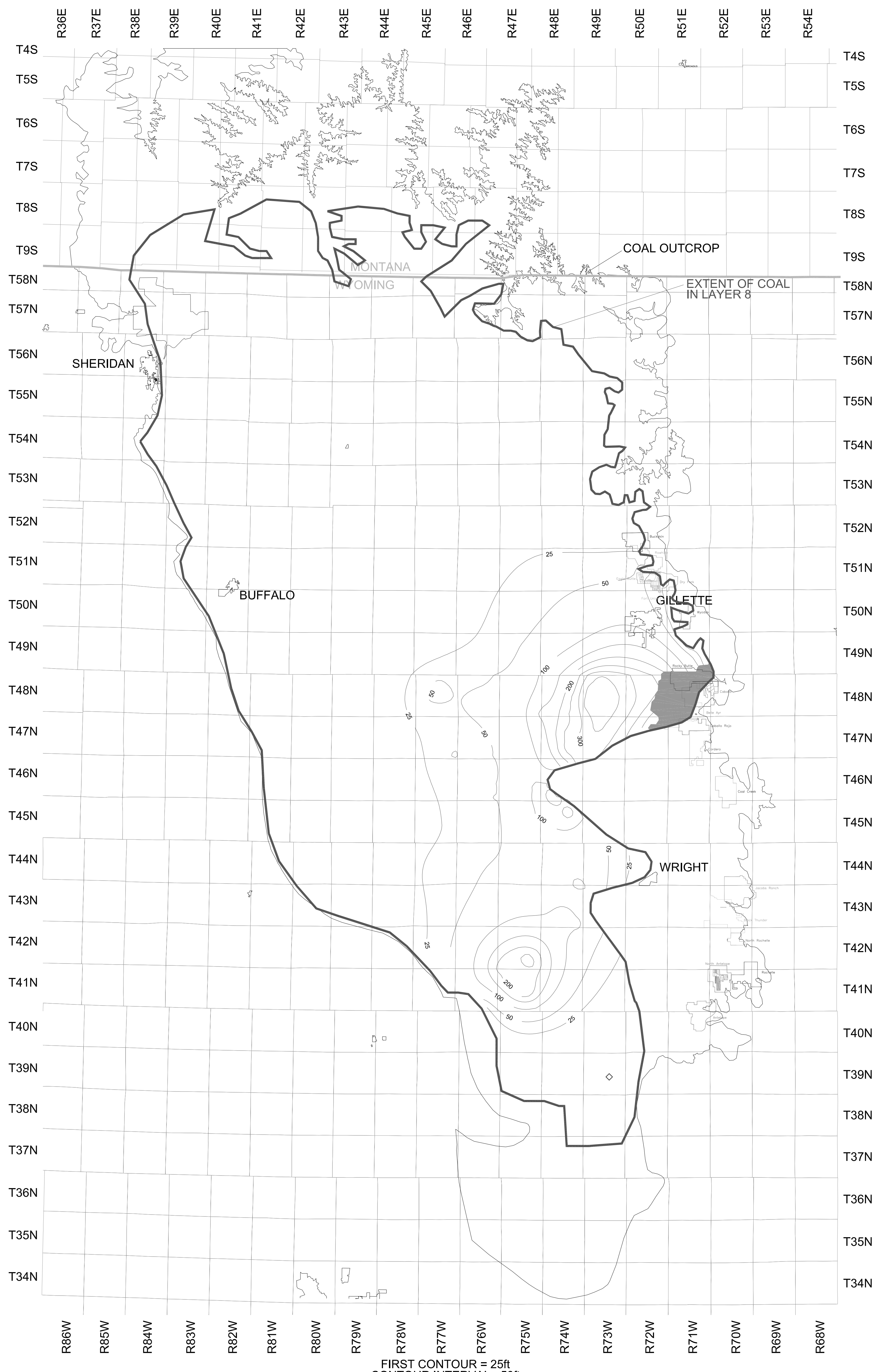
One consideration in model calibration is that modeled groundwater discharge rates must be consistent with observations of groundwater discharges to surface drainages. As discussed previously, the Powder River valley between Sussex, Wyoming, and Moorhead, Montana, has been interpreted as a significant groundwater discharge area (Hagmaier 1971), but Rankl and Lowry (1990) found no measurable effect of regional groundwater discharge on streamflow in this reach. A water balance analysis performed to estimate the potential baseflow to the Powder River in this reach was described in Section 2.3.2. This analysis, summarized in Table 2-3, concluded that regional groundwater discharge to the Powder River is in the range of 5 cfs to perhaps as high as 20 cfs. The water balance of the steady-state model indicates a net discharge of groundwater of approximately 15 cfs to the Powder River and its lower tributaries. This discharge is within the range of values estimated by the water balance analysis.

5.1.3 Transient-State Calibration to Water Levels

Transient model runs were conducted and compared with actual water levels for post-mining and post-CBM development conditions. Calibration was conducted iteratively with steady-state pre-mining conditions by adjusting the model input parameters, primarily: recharge rates, hydraulic conductivity, and storativity values. The final calibration for both steady-state and transient-state runs yielded consistent values for all hydrologic parameters.

Figures 5-4A, 5-4B, 5-4C, and 5-4D show the modeled changes in regional potentiometric surface for the model layers that represent coal deposits in the upper portion of the Fort Union Formation between 1975 and 2000. The extent and magnitude of modeled drawdown shown in these figures compare favorably with estimated actual drawdowns for selected BLM monitoring wells shown in Figure 2-4. The monitoring record for several of the BLM monitoring wells is relatively short, so that drawdown caused by earlier CBM or mining activity may not have been recorded in some areas. Interpreted drawdown in these wells, based on presumed initial static water levels that are already affected, would lead to underestimation of drawdown. This interpreted drawdown may account for some of the differences in modeled versus interpreted potentiometric drawdown.

Figures 5-5, 5-6, and 5-7 focus on three areas where there have been significant mining and CBM development, showing superimposed drawdown predicted by the model and drawdowns monitored near coal mines as of 1995 for comparison. The interpreted drawdown contours on these maps are from the 15-year drawdown report prepared for GAGMO. For all these maps, the modeled drawdown presented is of the model layer where the mines are located.



LEGEND

- Drawdown (ft) Upper Ft. Union Coals
- Extent of Coal in Layer 8
- Dry Cell
- Towns
- Mine Boundary

Note: Contours are not closed due to insufficient data.

N

0 7.5 15 30 Miles

POWDER RIVER BASIN
OIL & GAS PROJECT FEIS

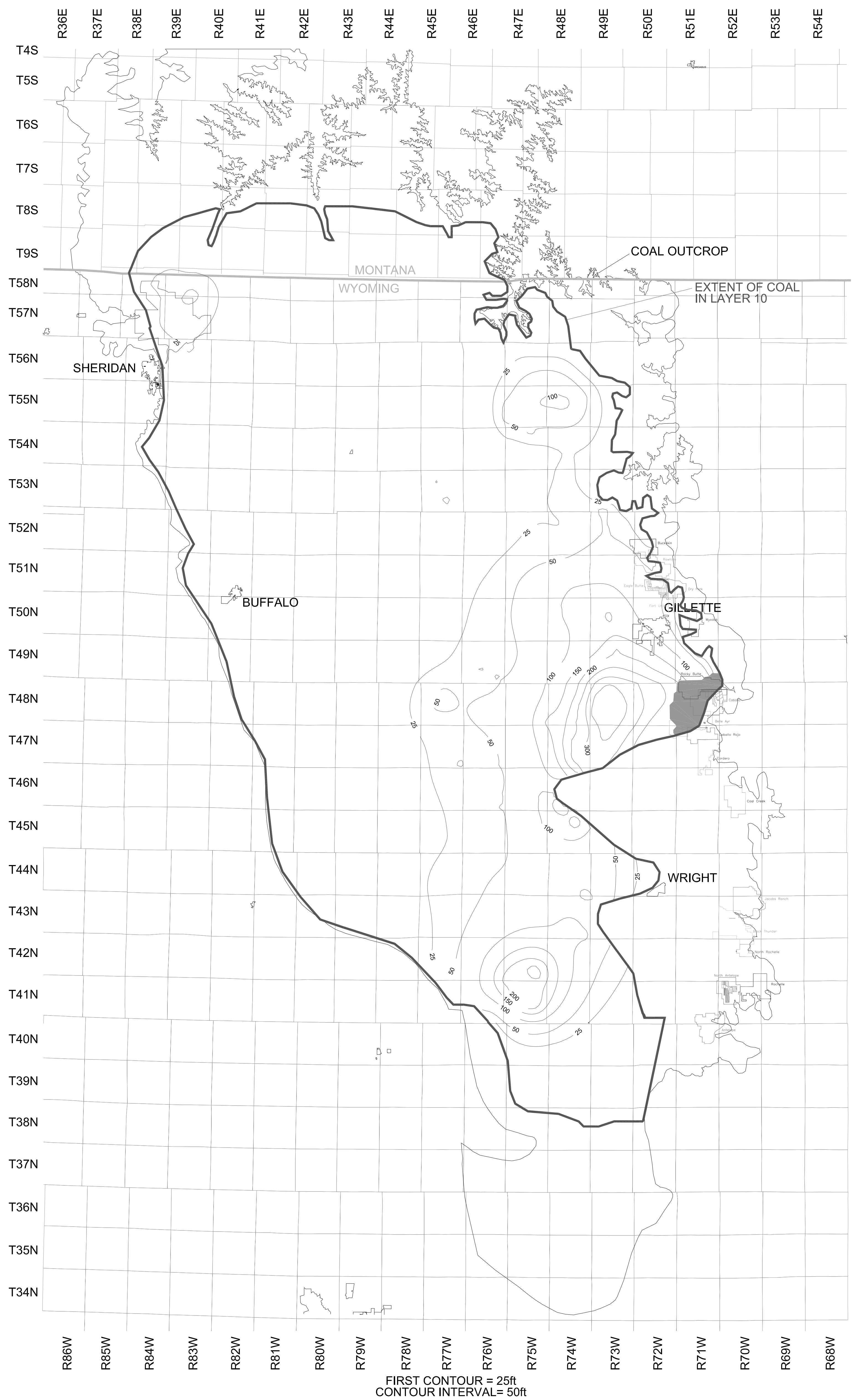
TECHNICAL REPORT GROUNDWATER MODELING

FIGURE 5-4A
MODELED DRAWDOWN
UPPER FORT UNION COALS
LAYER 8 YEAR 2000

MODEL RUN: From 1999-2200 (08-26-02)

Date: 09/04/02	Drawing File: Figure 5-4 a-d.dwg
Scale: As Noted	Drawn By: ETC

Figure 5-4A continued (11x17)



LEGEND

- Drawdown (ft) Upper Ft. Union Coals
- Extent of Coal in Layer 10
- Dry Cell
- Towns
- Mine Boundary

Note: Contours are not closed due to insufficient data.

N

0 7.5 15 30 Miles

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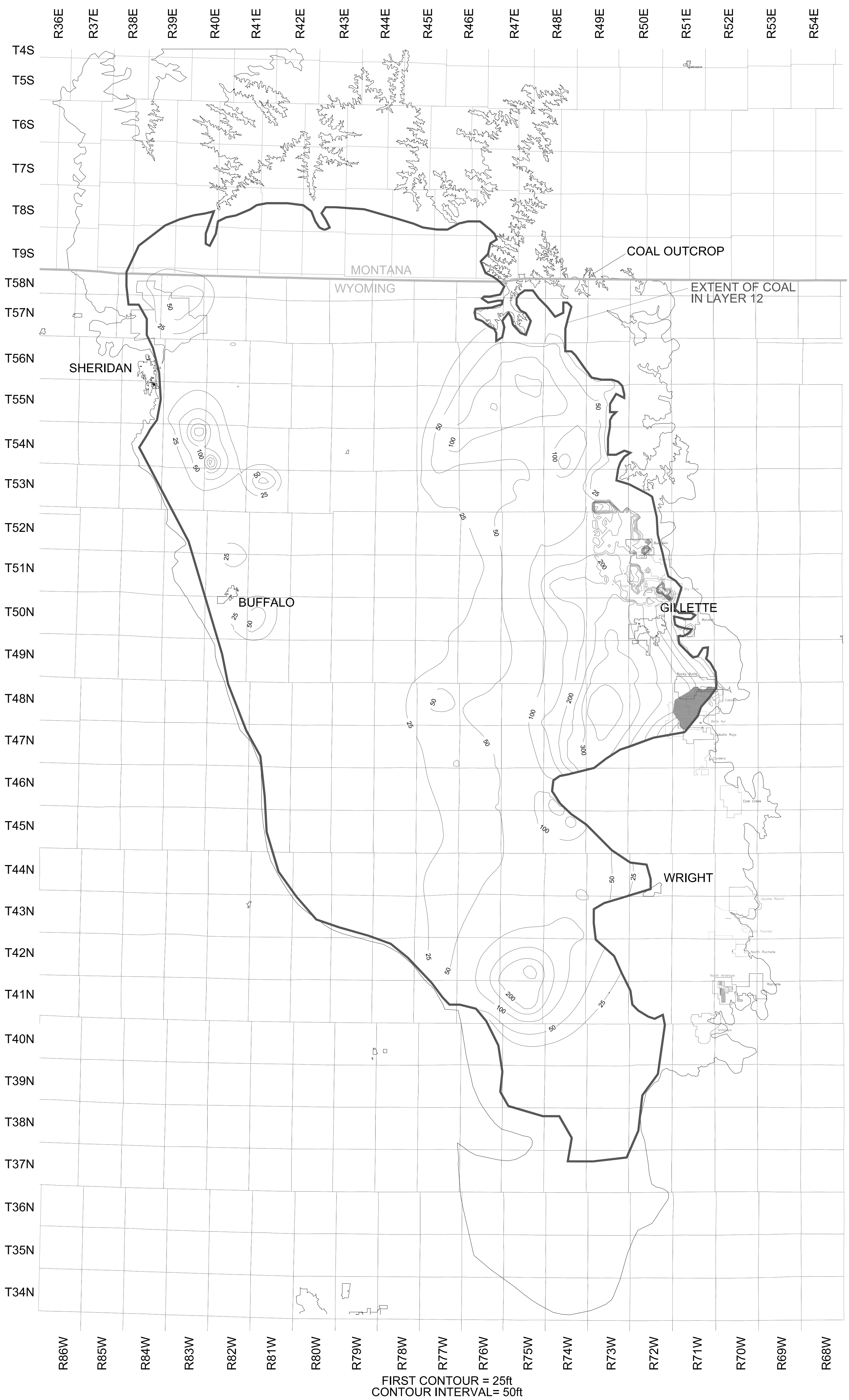
FIGURE 5-4B
MODELED DRAWDOWN
UPPER FORT UNION COALS
LAYER 10 YEAR 2000

MODEL RUN: From 1999-2200 (08-26-02)

Date: 09/04/02	Drawing File: Figure 5-4 a-d.dwg
Scale: As Noted	Drawn By: ETC

Figure 5-4B continued (11x17)



LEGEND

- Drawdown (ft) Upper Ft. Union Coals
- Extent of Coal in Layer 12
- Dry Cell
- Towns
- Mine Boundary

Note: Contours are not closed due to insufficient data.

N

0 7.5 15 30 Miles

POWDER RIVER BASIN OIL & GAS PROJECT FEIS

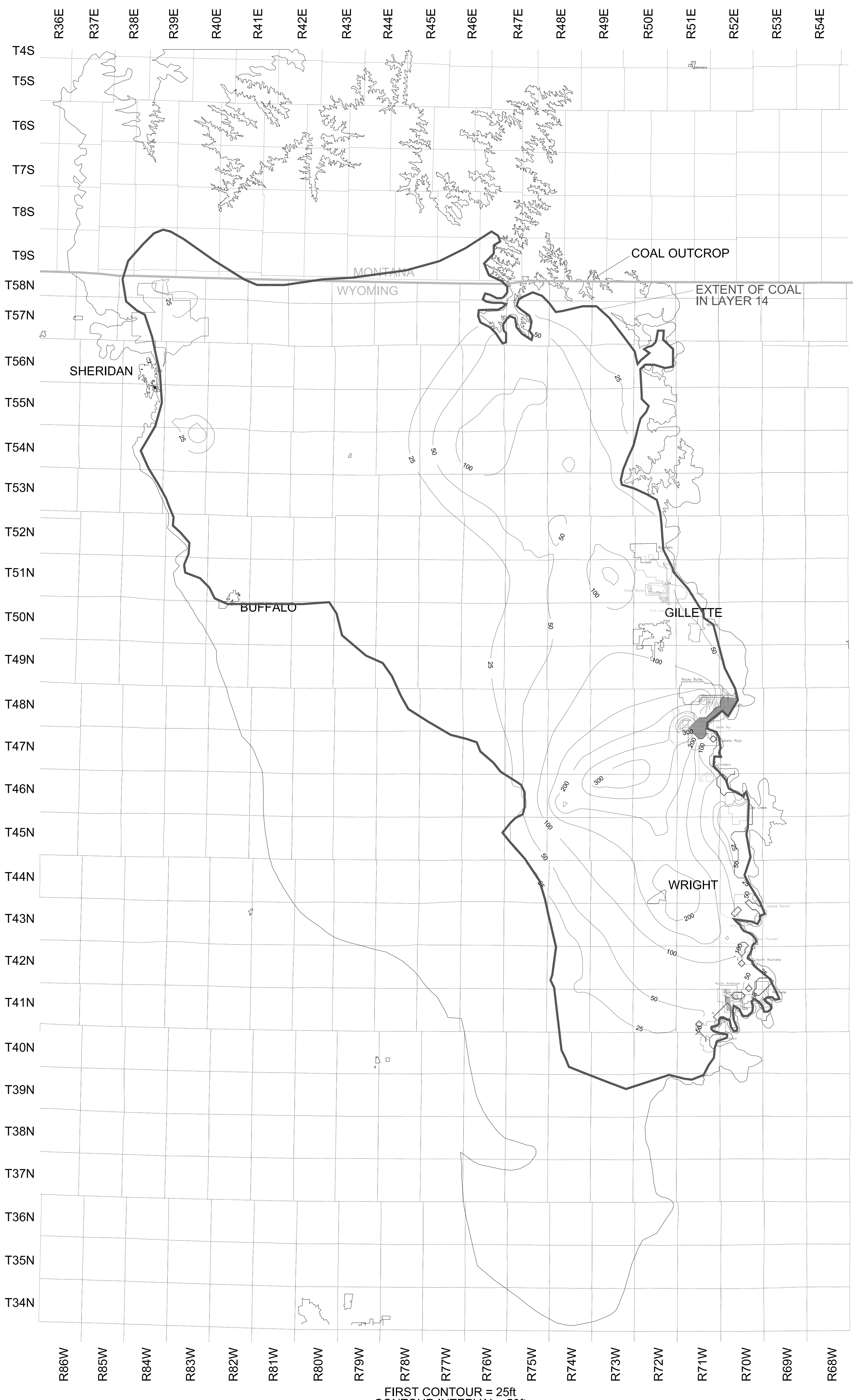
TECHNICAL REPORT GROUNDWATER MODELING

FIGURE 5-4C
MODELED DRAWDOWN
UPPER FORT UNION COALS
LAYER 12 YEAR 2000

MODEL RUN: From 1999-2200 (08-26-02)

Date: 09/04/02	Drawing File: Figure 5-4 a-d.dwg
Scale: As Noted	Drawn By: ETC

Figure 5-4C continued (11x17)



LEGEND

- Drawdown (ft) Upper Ft. Union Coals
- Extent of Coal in Layer 14
- Dry Cell
- Towns
- Mine Boundary

Note: Contours are not closed due to insufficient data.

N

0 7.5 15 30 Miles

POWDER RIVER BASIN
OIL & GAS PROJECT FEIS

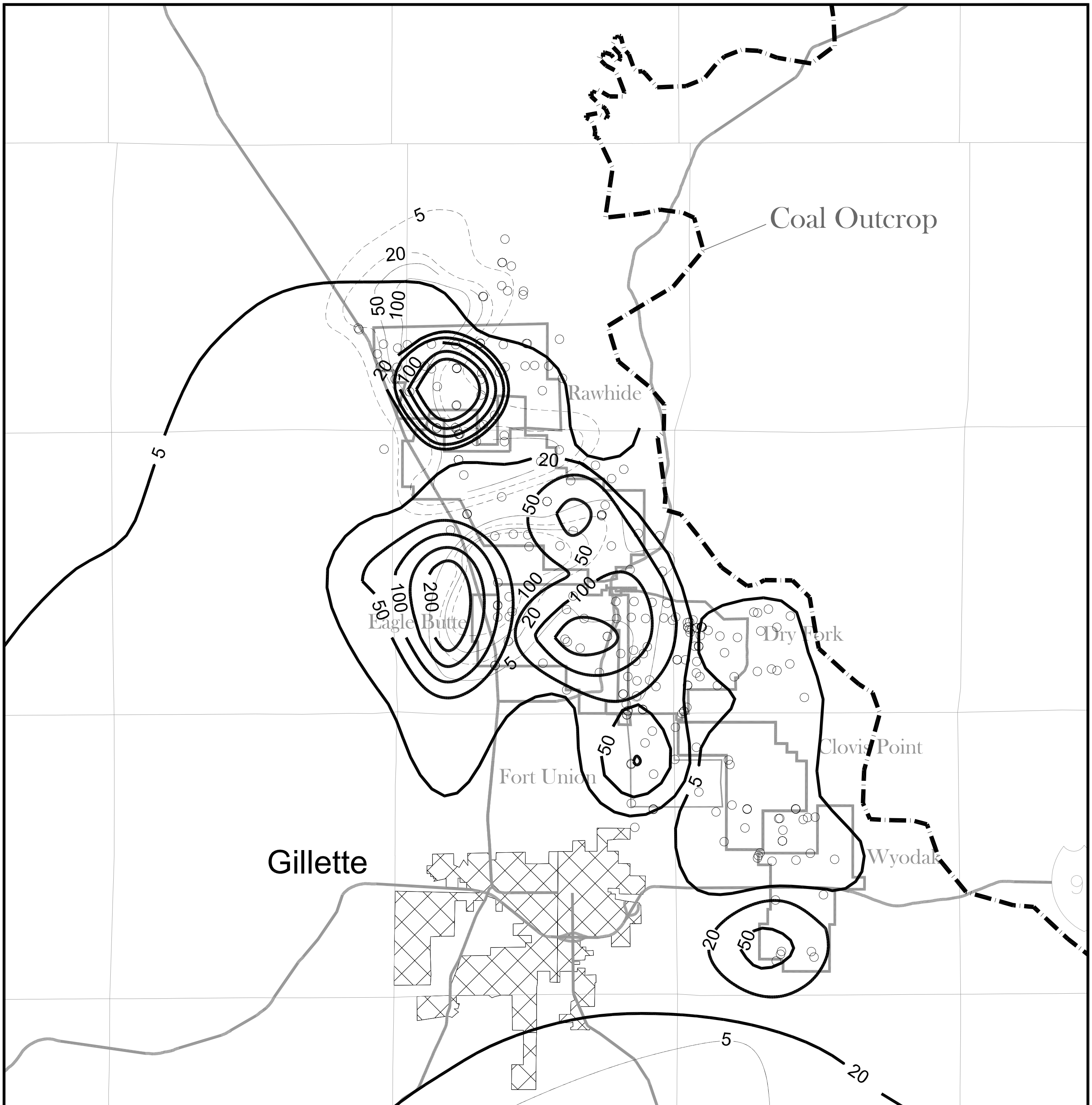
TECHNICAL REPORT GROUNDWATER MODELING

FIGURE 5-4D
MODELED DRAWDOWN
UPPER FORT UNION COALS
LAYER 14 YEAR 2000

MODEL RUN: From 1999-2200 (08-26-02)

Date: 09/04/02	Drawing File: Figure 5-4 a-d.dwg
Scale: As Noted	Drawn By: ETC

Figure 5-4D continued (11x17)



LEGEND

- ○ GAGMO Monitoring Wells
- Coal Lease Boundary
- Population Area
- GAGMO 15 Year Coal Seam Water Level Changes (Ft.)
- Modeled 1975-1995 Coal Seam Water Level Changes (Ft.)
- Coal Outcrop

N

0 1.5 3 6 Miles

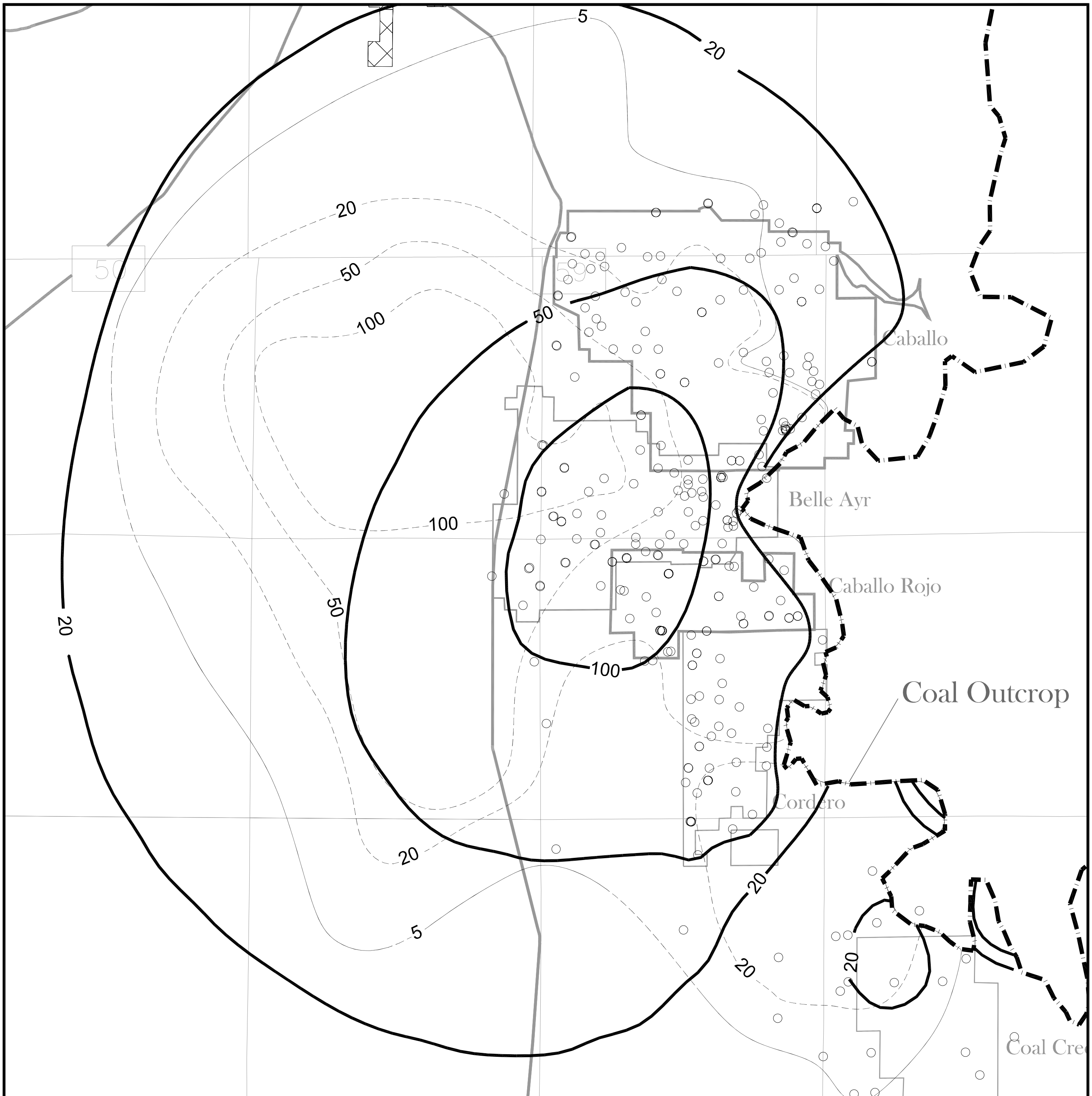
POWDER RIVER BASIN OIL & GAS PROJECT FEIS

TECHNICAL REPORT GROUNDWATER MODELING

FIGURE 5-5
MODELED vs ACTUAL DRAWDOWN IN UPPER FORT UNION COALS IN 1995
NORTHEAST AREA

MODEL RUN: From 1999-2200 (08-26-02)

Date: 09/04/02	Drawing File: Figure 5-5_5-7.dwg
Scale: As Noted	Drawn By: ETC



LEGEND

- GAGMO Monitoring Wells
- Coal Lease Boundary
- Population Area
- GAGMO 15 Year Coal Seam Water Level Changes (Ft.)
- Modeled 1975-1995 Coal Seam Water Level Changes (Ft.)
- Coal Outcrop

N

0 1.5 3 6 Miles

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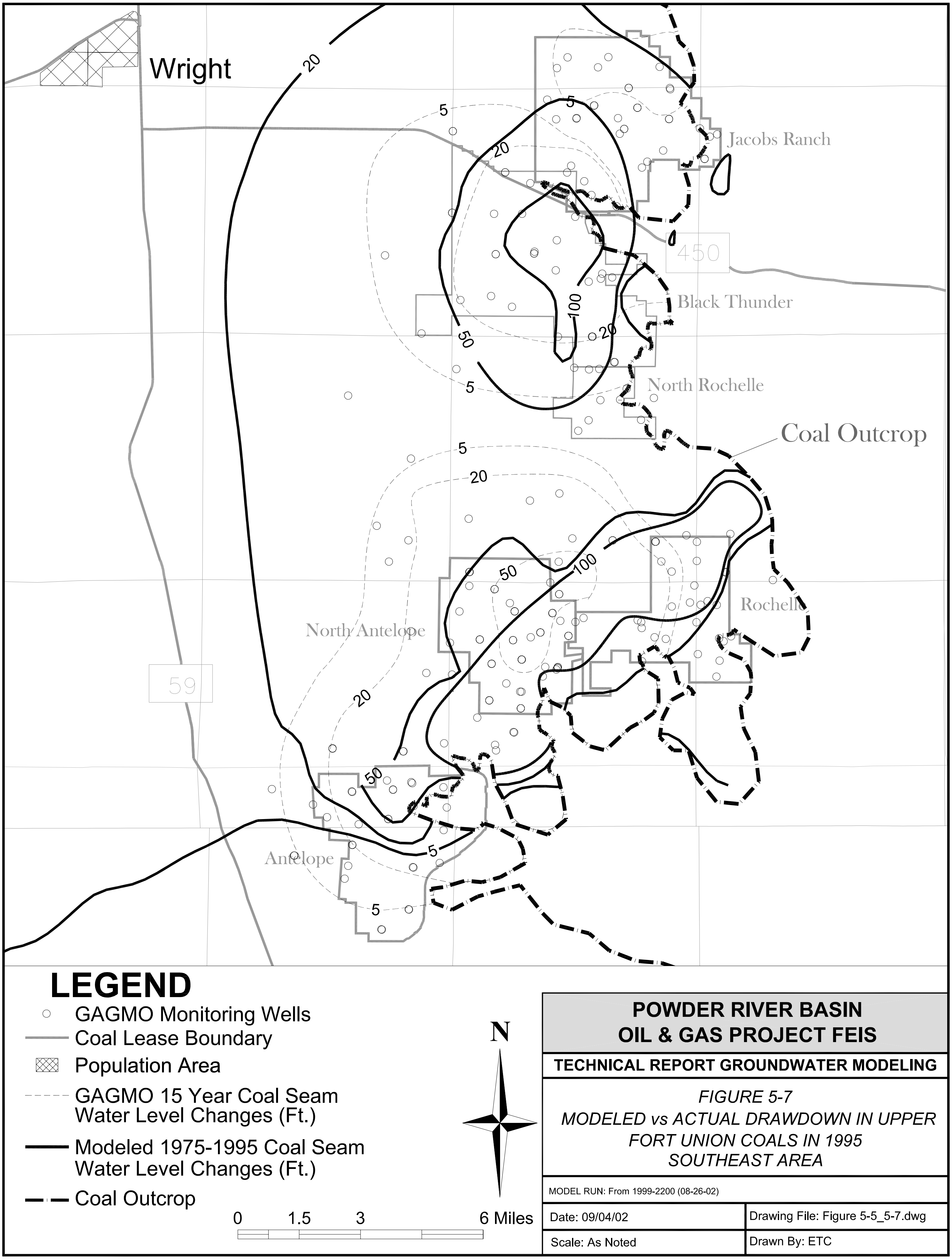
TECHNICAL REPORT GROUNDWATER MODELING

FIGURE 5-6
MODELED vs ACTUAL DRAWDOWN IN UPPER FORT UNION COALS IN 1995
CENTRAL-EAST AREA

MODEL RUN: From 1999-2200 (08-26-02)

Date: 09/04/02	Drawing File: Figure 5-5_5-7.dwg
Scale: As Noted	Drawn By: ETC



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TECHNICAL REPORT GROUNDWATER MODELING

FIGURE 5-7
MODELED vs ACTUAL DRAWDOWN IN UPPER FORT UNION COALS IN 1995
SOUTHEAST AREA

Most of the mining in the PRB was initiated after 1977 (with the exception of the Wyodak and Belle Ayr mines), so that use of 1975 as the baseline year (pre-mining) is reasonable. It may, however, result in some overestimation of drawdown in the model compared with the GAGMO interpretation, for the reasons described in Section 5.1.1. The extent of drawdown predicted by the model in the three localized areas shown in Figures 5-5, 5-6, and 5-7 compares reasonably well with the drawdowns interpreted by GAGMO. The level of accuracy used for calibration is believed to be reasonable in light of the regional nature of the model with a grid spacing of about one-half mile. The model should not be expected to match water levels accurately at a smaller scale, such as a mine site.

The extent of drawdown projected by the model, represented by the 5-foot drawdown contour, tends to be more extensive than the GAGMO interpretation in the northeast and southeast areas (Figures 5-5 and 5-7). This larger extent may be caused in part because the drawdown projected by the model uses 1975 as the base year, while the GAGMO-interpreted drawdown uses 1980 as the base year. The model also accounts for drawdown in the coal that occurs as a result of pumping of the underlying Fort Union sands by the City of Gillette and the town of Wright, which began before 1980. The model's incorporation of drawdown has the effect of imposing a small amount of coal drawdown (5 to 10 feet) over an extended area above these well fields. The drawdown in the vicinity of the mines compares closely.

The extent of drawdown predicted by the model in the Marquiss area located west of the Belle Ayr Mine, represented by the 20-foot drawdown contour, is similar to the level actually observed, as shown in Figure 5-6. The extended drawdown area located west of the mine areas is caused by the initiation of CBM activity in 1992. Continued CBM development in the Marquiss field since 1995 has caused drawdowns in this area to increase to more than 250 feet. Overall, the calibrated model effectively simulates groundwater flow conditions in these local areas under the superimposed stresses of mining and CBM development.

Figures 5-8 through 5-11 show modeled versus actual drawdown over time in selected BLM monitoring wells where there is evidence of drawdown caused by CBM activity. The MP-22 and MP-2 wells (Figures 5-8 and 5-9) are located west of the Belle Ayr mine and south of Gillette. The Prairie Dog monitoring well (Figure 5-10) is located near Sheridan, and BLM well no. 447131 (Figure 5-11) is located in the southeastern part of the PRB. Generally, the graphs show reasonable agreement between modeled and actual drawdown over time, although the Prairie Dog monitoring well (Figure 5-10) shows considerably more drawdown than is predicted by the model. The regional nature of the model tends to smooth and average predicted drawdown effects attributed to depressurization. This effect tends to be most apparent in areas of relatively isolated CBM development, such as the Prairie Dog area.

5.1.4 Transient State Calibration to CBM Water Production

The CBM wells were simulated using "drain" nodes that turn on and off corresponding to actual pumping schedules for existing wells, and an assumed schedule of 7 years for proposed (future) wells. A single drain node may represent one or more wells because the node spacing in the model is one-half mile by one-half mile.

The rate of water production in an active drain will decline over time because the elevation of the water level in the drain cannot drop below a fixed elevation, assigned at 16 feet (5 meters) above the top of the highest coal seam being developed in that area. The water flow to the drain declines as the head declines in the model nodes that surround the drain. This decline simulates the process that occurs in CBM production wells.

The rate water flows toward a drain node from an adjacent node depends on:

1. The difference in head between the drain node and the adjacent node (time variable)
2. The hydraulic conductivity and thickness of the nodes (transmissivity)
3. The conductance assigned to the drain node

During calibration, the conductances of the drain nodes were varied to match historical production data reported to WOGCC at the CBM wells represented by the drain.

- A number of CBM well clusters with adequate production data were selected to represent individual drain nodes in the model for calibration. Criteria for selection included:

  - Wells with historical production data that spanned at least 10 months of any year were selected. Shorter production periods were considered only if wells with at least 10 months of data did not exist in a watershed.
  - Where possible, well clusters that covered the range of long-term CBM development areas as well as relatively "new" CBM development areas were selected.
  - Depending on the size of the watershed, three to five well clusters were selected.
  - Locations that covered the range of hydraulic conductivities and thicknesses assigned to the developed coal layers within the watershed were selected.
  - Well clusters that covered the range of well densities represented in the watershed were selected.
  - Well clusters where multiple and single coals are being developed were selected.

- Total production from these wells was normalized to a full 12 months for any years where the production data were less than 12 months.

- Individual "zone budget" areas were assigned for these calibration drain nodes. This zone budget allowed the model to track flows to the individual node.

- The drain node was calibrated by varying the drain conductance parameter to match the normalized historical production for the wells represented by the drain node.

- When a reasonable match was obtained for each watershed (within 20 percent), an average "drain conductance per well" was calculated based on the number of wells represented by each calibration drain in the watershed.

- A drain conductance was applied for existing and future drains in the model based on the average "drain conductance per well" for the watershed multiplied by the number of wells represented by the drain node.

Drain conductances per well was assumed to be similar to calibrated drains in other watersheds where coal thickness and hydraulic conductivity are similar for watersheds where little or no historical data on CBM production is available that can be used for calibration.

After the initial drain conductance was calibrated for the 2001 version of the model, BLM provided estimated production numbers for each watershed using representative production curves for each watershed, based on the updated WOGCC database. The CBM drain conductances in the model were modified to calibrate more closely to the watershed-wide estimates of produced water projected by the representative production curves provided by the BLM.

5.2 Sensitivity Analysis

A sensitivity analysis was used to evaluate the effects of changes in model parameters on model calibration. The "base" (calibrated) conditions reflect the most likely hydrogeologic conditions, as they were developed from site-specific field data.The most sensitive factors for both the steady-state and transient models were location and quantity of recharge, and permeability in both the horizontal and vertical directions. In the transient mode, storativity also was also a sensitive parameter.

It is necessary to use a vertical hydraulic conductivity for the intervening confining unit of between $2x10^{-9}$ to $6x10^{-11}$ ft/sec to match the fairly large difference in head observed between the overburden sands and the coal units under the current conditions. Similarly, the observed potentiometric drawdown induced by CBM operations within the coal could be matched only if a regional conductivity of between $1xl0^{-4}$ and $6x10^{-5}$ ft/sec is assumed. This range of values is considerably less than might be expected from individual well testing. However, the existence of high amounts of released methane in the coal, induced by the lowered potentiometric pressures, will result in an effectively lower permeability to water.

One limitation of the MODFLOW code is that it does not allow hydraulic conductivity to vary as a function of pressure. Accordingly, the values for hydraulic conductivity that may be appropriate for steady-state calibration to pre-mining conditions may be over-estimated for transient calibration in areas of significant potentiometric drawdown.

A regional recharge rate of 0.03 inches per year must be assumed to achieve reasonable global water balance and match water levels in overburden sands. Increased recharge in the clinker of 0.1 to 0.6 inches per year was used to match the higher water levels found adjacent to these areas. The relatively low regional recharge rate appears inconsistent with the relatively high rates of infiltration seen in creek areas. However, the regional recharge rate is a representation of the recharge if it were to occur uniformly over the area. As the creeks constitute a small percentage of the total area (probably less than 1 percent), the equivalent areal recharge value is small. In addition, only a fraction (probably less than 20 percent) of the total precipitation falling on the land surface actually runs off into a creek drainage where it can then effectively infiltrate. It is likely that precipitation that does not become runoff makes no significant contribution to groundwater recharge (except in highly permeable zones such as clinker areas) because it is consumptively used by vegetation or evaporates (or sublimates) back to the atmosphere.

Figure 5-8 Modeled vs. Actual Drawdown Graphs for BLM MP-22 Monitoring Wells (West of Belle Ayr Mine South of Gillette)

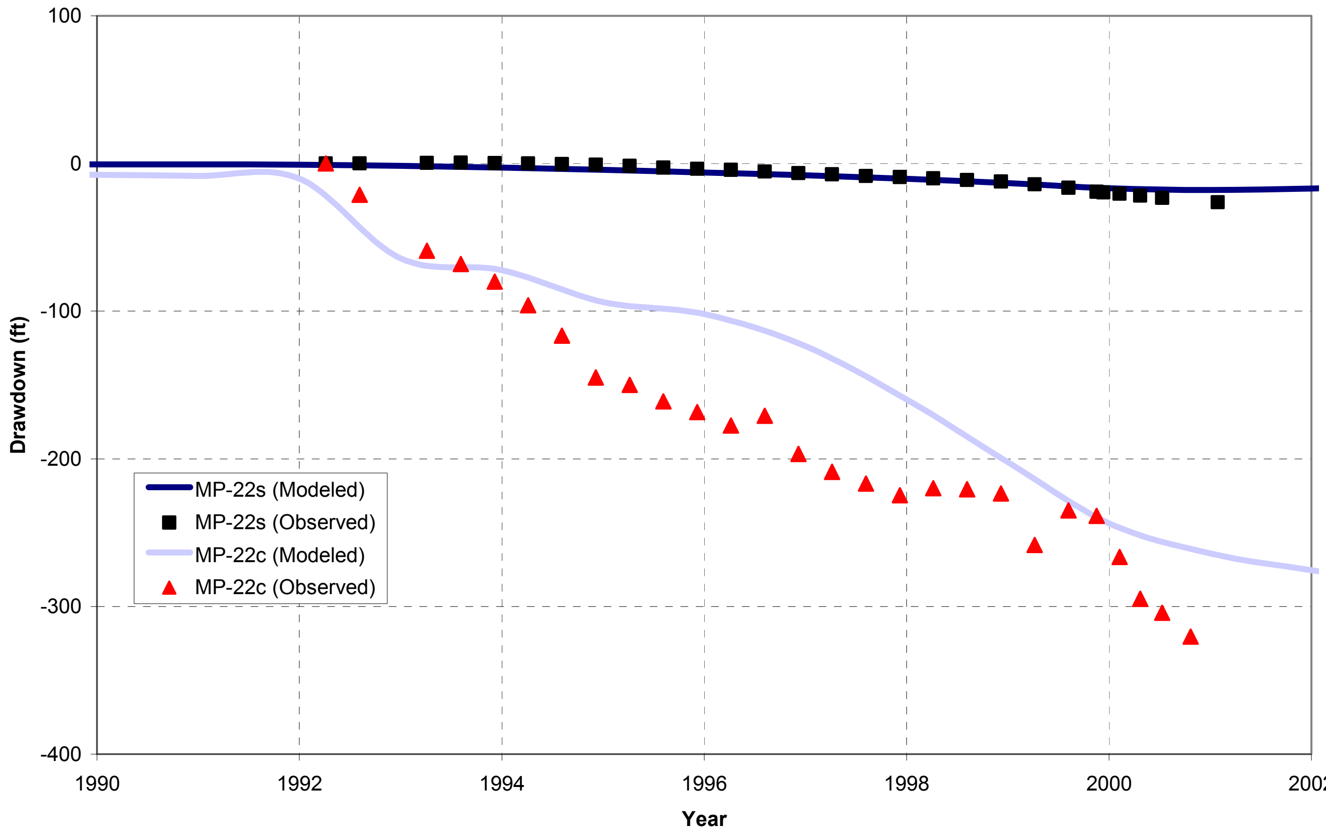

Figure 5-9 Modeled vs. Actual Drawdown Graphs for BLM MP-2 Monitoring Wells (West of Belle Ayr Mine South of Gillette)

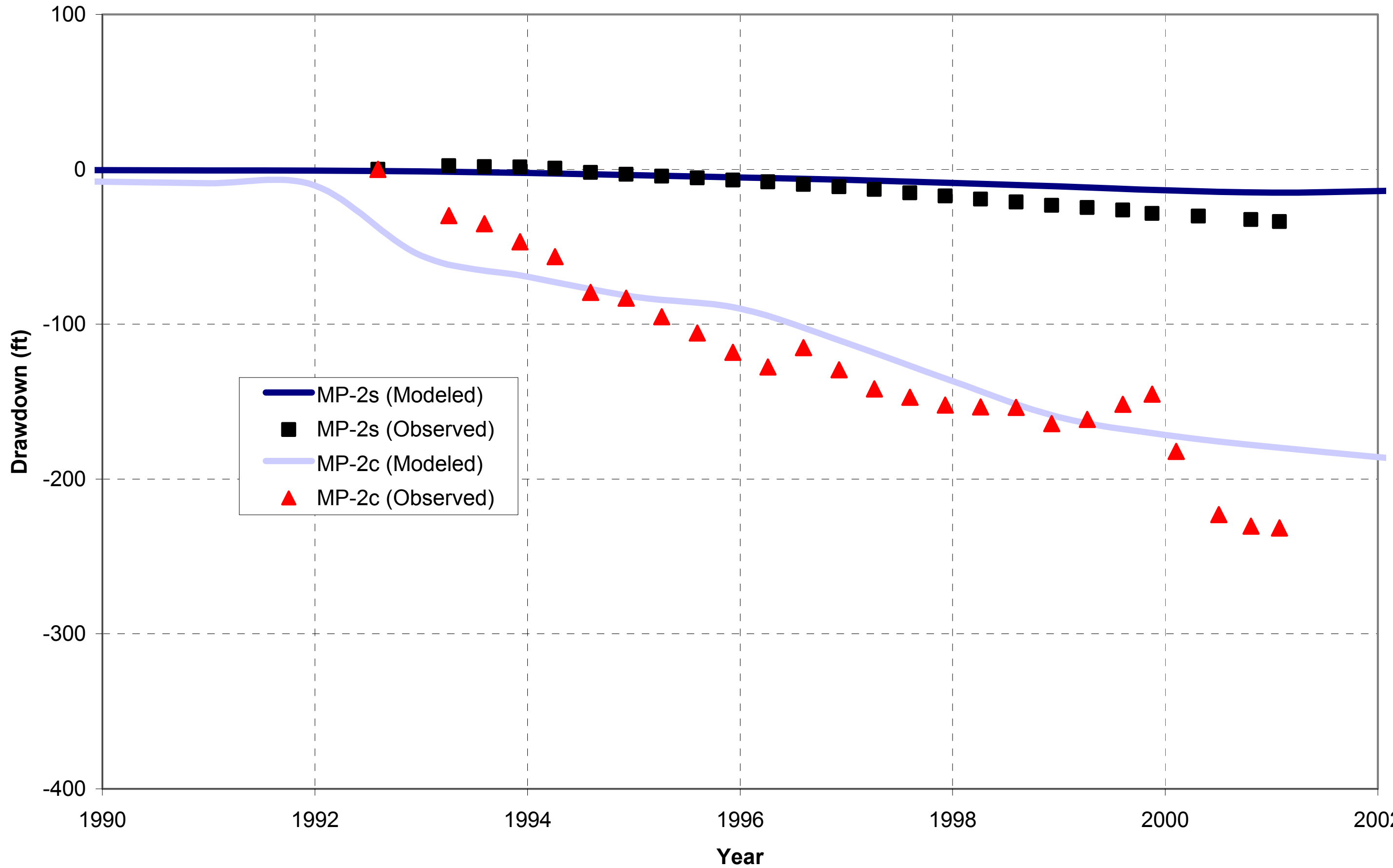

Figure 5-10 Modeled vs. Actual Drawdown Graphs for BLM Prairie Dog Monitoring Well (Near Sheridan)

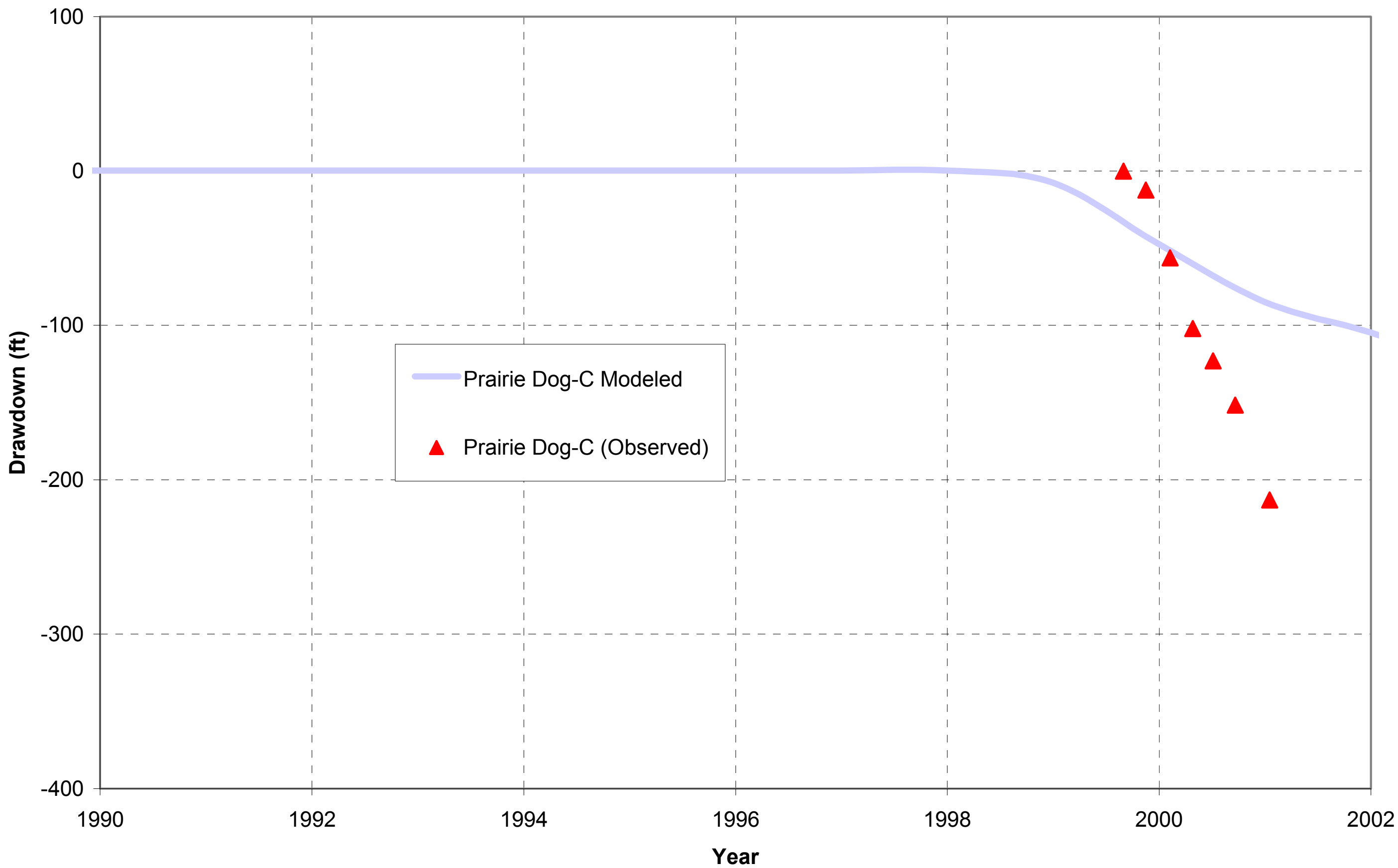

Figure 5-11 Modeled vs. Actual Drawdown Graphs for BLM 447131 Monitoring Well (Southeastern Powder River Basin)