

**POWERTECH (USA) INC.**

**Dewey-Burdock Project  
Application for NRC  
Uranium Recovery License  
Fall River and Custer Counties,  
South Dakota  
Technical Report**

**Appendices  
Volume III  
Appendix 2.7-J – 2.8-H**

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*Prepared for*  
**U.S. Nuclear Regulatory Commission  
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**APPENDIX 2.7-J**

**TVA GROUNDWATER QUALITY DATA**

**Table C-1. Historic Water-Quality Data From Well #2**

| <b>Analyte</b>                         | <b>6/15/1979</b> | <b>10/6/1980</b> | <b>1/16/1981</b> | <b>4/6/1981</b> | <b>7/6/1981</b> | <b>10/19/1981</b> | <b>4/12/1982</b> | <b>7/26/1982</b> | <b>4/11/1983</b> | <b>4/17/1984</b> |
|--|------------------|------------------|------------------|-----------------|-----------------|-------------------|------------------|------------------|------------------|------------------|
| Alkalinity (mg/L)                      | 200              | 229              | 218              | 220             | 218             | 210               | 220              | 242              | 220              | 218              |
| Arsenic (mg/L)                         | <0.01            | <0.005           | <0.005           | <0.005          | <0.005          | <0.005            | 0.021            | <0.005           | <0.005           | <0.005           |
| Bicarbonate as HCO <sub>3</sub> (mg/L) | 171              | 229              | 218              | 220             | 218             | 210               | 220              | 242              | 220              | 218              |
| Boron (mg/L)                           | <1               |                  |                  |                 |                 |                   |                  |                  |                  |                  |
| Calcium (mg/L)                         | 50               | 60               | 86               | 91              | 64              | 63                | 46               | 49               | 51               | 50               |
| Carbonate (mg/L)                       | 36               |                  |                  |                 |                 |                   |                  |                  |                  |                  |
| Cation/Anion Balance (%)               | -67.8            |                  |                  |                 |                 |                   |                  |                  | 0.8              | 2.86             |
| Chlorine (mg/L)                        | 16               | 5.5              | 9                | 10              | 10              | 9                 | 10               | 8                | 11               | 10               |
| Conductivity (umhos)                   | 1450             | 1525             | 1530             | 1475            | 1520            | 1505              | 1590             | 1560             | 1570             | 1750             |
| hardness (mg/L)                        | 203              | 233              | 234              | 226             | 220             | 240               | 184              | 190              | 192              | 192              |
| Iron (mg/L)                            | 0.34             | 0.45             | 0.95             | 0.32            | 0.48            | 6.4               | 0.5              | 0.8              | 1.3              | 1.19             |
| Lead (mg/L)                            | <0.05            | <0.005           | <0.005           | <0.005          | <0.005          | 0.005             | <0.005           | <0.005           | <0.005           | <0.005           |
| Magnesium (mg/L)                       | 19               | 20               | 16               | 20              | 22              | 20                | 16               | 15               | 15               | 16               |
| Manganese (mg/L)                       | 0.14             | 0.1              | 0.28             | 0.1             | 0.1             | 0.25              | 0.15             | 0.1              | 0.09             | 0.09             |
| Nitrogen (mg/L)                        | 1.5              | <0.1             | 0.21             | 0.13            | <0.1            | 0.49              | 0.15             | <0.1             | 1.39             | 0.94             |
| pH                                     | 8.2              | 7.74             | 7.57             | 7.67            | 7.89            | 7.16              | 7.69             | 7.78             | 7.69             | 7.63             |
| Phosphate (mg/L)                       | <0.01            | <0.03            | <0.03            | <0.03           | 0.03            | 0.08              | 0.069            | 0.06             | 0.04             | <0.03            |
| Potassium (mg/L)                       | 16               | 15               | 16.6             | 16              | 13              | 16                | 15               | 14               | 14               | 14               |
| Radium 226 (pCi/L)                     |                  |                  |                  |                 | 1.04            |                   | 1.26             | 0.09             |                  | 0.5              |
| Selenium (mg/L)                        | <0.01            |                  |                  |                 |                 |                   |                  |                  | 297              |                  |
| Silicon (mg/L)                         | 7.3              | 4.44             | <1               | 9.4             | 6.42            | 8.6               | <2               | 9.2              | 8.7              | 9.73             |
| Sodium (mg/L)                          | 288              | 269              | 251              | 264             | 280             | 244               | 306              | 300              | 297              | 318              |
| Sulfate (mg/L)                         | 604              | 415              | 536              | 556             | 556             | 626               | 580              | 582              | 574              | 590              |
| Total Dissolved Solids (mg/L)          | 1113             | 1030             | 1004             | 1039            | 1052            | 1008              | 1038             | 1062             | 1010             | 1074             |
| Total Suspended Solids (mg/L)          | 1.6              | 1                | 1                | <1              | <1              | 22                | <1               | <1               | 3                | 5                |
| Uranium (ug/L)                         |                  |                  |                  |                 | 0.007           |                   | 1.6              | 0.4              |                  |                  |
| Vanadium (mg/L)                        | <0.05            |                  |                  |                 |                 |                   |                  |                  |                  |                  |
| Zinc (mg/L)                            | 0.01             | 0.005            | <0.01            | <0.01           | <0.01           | <0.01             | <0.03            | <0.01            | <0.03            | <0.005           |



**Table C-2. Historic Water-Quality Data From Well #7**

| Analyte                                | 6/15/1979 | 8/10/1979 | 9/12/1979 |
|--|-----------|-----------|-----------|
| Alkalinity (mg/L)                      | 191       |           | 171       |
| Arsenic (mg/L)                         | <0.01     |           | <0.01     |
| Bicarbonate as HCO <sub>3</sub> (mg/L) | 159       |           | 37        |
| Boron (mg/L)                           | <1        |           | <1        |
| Calcium (mg/L)                         | 33        |           | 38        |
| Carbonate (mg/L)                       | 36        |           | 84        |
| Cation/Anion Balance (%)               | -73.2     |           | -64.9     |
| Chlorine (mg/L)                        | 18        |           | 6         |
| Conductivity (umhos)                   | 1350      |           | 1325      |
| hardness (mg/L)                        | 153       |           | 182       |
| Iron (mg/L)                            | 0.48      |           | 0.5       |
| Lead (mg/L)                            | <0.05     |           | <0.05     |
| Magnesium (mg/L)                       | 17        |           | 21        |
| Manganese (mg/L)                       | 0.04      |           | 0.03      |
| Nitrogen (mg/L)                        | 2.3       |           | 0.39      |
| pH                                     | 8.3       |           | 8.7       |
| Phosphate (mg/L)                       | <0.01     |           | <0.01     |
| Potassium (mg/L)                       | 15        |           | 14        |
| Radium 226 (pCi/L)                     |           | 1         |           |
| Selenium (mg/L)                        | <0.01     |           | <0.01     |
| Silicon (mg/L)                         | 6.6       |           | 6.4       |
| Sodium (mg/L)                          | 307       |           | 277       |
| Sulfate (mg/L)                         | 600       |           | 600       |
| Total Dissolved Solids (mg/L)          | 1104      |           | 1058      |
| Total Suspended Solids (mg/L)          | 1.2       |           | 3.2       |
| Uranium (ug/L)                         |           |           |           |
| Vanadium (mg/L)                        | <0.05     |           | <0.05     |
| Zinc (mg/L)                            | 0.08      |           | 0.08      |

**Table C-3. Historic Water-Quality Data From Well #8**

| <b>Analyte</b>                         | <b>6/15/1979</b> | <b>8/14/1979</b> | <b>9/12/1979</b> | <b>10/6/1980</b> | <b>1/6/1981</b> | <b>4/8/1981</b> | <b>7/6/1981</b> | <b>10/19/1981</b> | <b>4/12/1982</b> | <b>7/26/1982</b> | <b>4/11/1983</b> | <b>4/17/1984</b> |
|--|------------------|------------------|------------------|------------------|-----------------|-----------------|-----------------|-------------------|------------------|------------------|------------------|------------------|
| Alkalinity (mg/L)                      | 170              | 0                | 180              | 181              | 166             | 182             | 176             | 184               | 170              | 194              | 178              | 177              |
| Arsenic (mg/L)                         | <0.01            | 0                | <0.01            | <0.005           | <0.005          | <0.005          | <0.005          | <0.005            | <0.005           | <0.005           | <0.005           | <0.005           |
| Bicarbonate as HCO <sub>3</sub> (mg/L) | 207              | 0                | 195              | 181              | 166             | 182             | 148             | 184               | 170              | 194              | 178              | 177              |
| Boron (mg/L)                           | <1               | 0                | <1               | 0                | 0               | 0               | 0               | 0                 | 0                | 0                | 0                | 0                |
| Calcium (mg/L)                         | 52               | 0                | 58               | 52               | 74              | 79              | 55              | 55                | 59               | 60               | 54               | 60               |
| Carbonate (mg/L)                       | 0                | 0                | 12               | 0                | 0               | 0               | 28              | 0                 | 0                | 0                | 0                | 0                |
| Cation/Anion Balance (%)               | -66.7            | 0                | -64.1            | 0                | 0               | 0               | 0               | 0                 | 0                | 0                | 0.03             | 3.71             |
| Chlorine (mg/L)                        | 16               | 0                | 16               | 9                | 9               | 12              | 12              | 13                | 11               | 8.5              | 12               | 12               |
| Conductivity (umhos)                   | 1285             | 0                | 1300             | 1450             | 1430            | 1375            | 1400            | 1380              | 1425             | 1390             | 1390             | 1410             |
| hardness (mg/L)                        | 233              | 0                | 243              | 229              | 264             | 216             | 218             | 220               | 248              | 232              | 260              | 266              |
| Iron (mg/L)                            | 0.71             | 0                | 0.13             | 0.25             | 0.46            | 0.26            | 0.15            | 0.3               | 0.25             | 0.17             | 0.26             | 0.25             |
| Lead (mg/L)                            | <0.05            | 0                | <0.05            | <0.005           | <0.005          | <0.005          | <0.005          | <0.005            | <0.005           | <0.005           | <0.005           | <0.005           |
| Magnesium (mg/L)                       | 25               | 0                | 24               | 25               | 22              | 22              | 25              | 23                | 26               | 22               | 24               | 26               |
| Manganese (mg/L)                       | 0.11             | 0                | 0.08             | 0.08             | 0.23            | 0.09            | 0.07            | 0.13              | 0.14             | 0.08             | 0.09             | 0.1              |
| Nitrogen (mg/L)                        | 2.9              | 0                | 0.29             | 0.1              | 0.15            | 1.62            | 0.1             | 1.23              | 0.24             | <0.1             | 0.81             | 0.17             |
| pH                                     | 8.5              | 0                | 8.3              | 7.8              | 7.74            | 7.85            | 8.08            | 7.59              | 7.62             | 7.67             | 7.74             | 7.64             |
| Phosphate (mg/L)                       | <0.01            | 0                | <0.01            | <0.03            | <0.03           | <0.03           | 0.03            | 0.03              | <0.03            | <0.03            | 0.03             | <0.03            |
| Potassium (mg/L)                       | 18               | 0                | 19               | 16               | 18.9            | 18              | 14              | 18                | 19               | 17               | 18               | 17               |
| Radium 226 (pCi/L)                     | 0                | 1.9              | 0                | 0                | 0               | 0               | 1.27            | 0                 | 1.37             | 1.44             | 0                | 1.6              |
| Selenium (mg/L)                        | <0.01            | 0                | <0.01            | 0                | 0               | 0               | 0               | 0                 | 0                | 0                | 218              | 0                |
| Silicon (mg/L)                         | 6.6              | 0                | 4.9              | 3.6              | <1              | 8.1             | 10.7            | 7.5               | <2               | 5.8              | 6.7              | 7.23             |
| Sodium (mg/L)                          | 277              | 0                | 265              | 226              | 215             | 232             | 245             | 210               | 218              | 253              | 218              | 242              |
| Sulfate (mg/L)                         | 640              | 0                | 616              | 400              | 504             | 536             | 488             | 520               | 520              | 514              | 520              | 530              |
| Total Dissolved Solids (mg/L)          | 1130             | 0                | 1106             | 918              | 942             | 972             | 974             | 904               | 904              | 964              | 860              | 942              |
| Total Suspended Solids (mg/L)          | 4.8              | 0                | 0.4              | 1                | 2               | 4               | 1               | 1                 | 2                | <1               | <1               | 5                |
| Uranium (ug/L)                         | 0                | 0                | 0                | 0                | 0               | 0               | 0.007           | 0                 | 0.8              | 2.2              | 0                | 1                |
| Vanadium (mg/L)                        | <0.05            | 0                | <0.05            | 0                | 0               | 0               | 0               | 0                 | 0                | 0                | 0                | 0                |
| Zinc (mg/L)                            | 0.01             | 0                | 0.01             | 0.005            | <0.01           | <0.01           | <0.01           | 0.01              | <0.03            | <0.01            | <0.03            | <0.005           |

**Table C-4. Historic Water-Quality Data From Well #13**

| <b>Analyte</b>                         | <b>6/15/1979</b> | <b>8/16/1979</b> | <b>9/12/1979</b> | <b>10/7/1980</b> | <b>1/13/1981</b> | <b>4/6/1981</b> | <b>7/6/1981</b> | <b>10/19/1981</b> | <b>4/12/1982</b> | <b>7/26/1982</b> | <b>4/11/1983</b> | <b>4/17/1984</b> |
|--|------------------|------------------|------------------|------------------|------------------|-----------------|-----------------|-------------------|------------------|------------------|------------------|------------------|
| Alkalinity (mg/L)                      | 160              |                  | 170              | 180              | 176              | 166             | 167             | 183               | 169              | 196              | 168              | 172              |
| Arsenic (mg/L)                         | <0.01            |                  | <0.01            | <0.005           | 0.009            | <0.005          | <0.005          | <0.005            | <0.005           | 0.005            | <0.005           | <0.005           |
| Bicarbonate as HCO <sub>3</sub> (mg/L) | 171              |                  | 207              | 180              | 176              | 166             | 167             | 183               | 169              | 196              | 168              | 172              |
| Boron (mg/L)                           | <1               |                  | <1               |                  |                  |                 |                 |                   |                  |                  |                  |                  |
| Calcium (mg/L)                         | 66               |                  | 74               | 66               | 102              | 103             | 67              | 70                | 68               | 65               | 67               | 69               |
| Carbonate (mg/L)                       | 12               |                  |                  |                  |                  |                 |                 |                   |                  |                  |                  |                  |
| Cation/Anion Balance (%)               | -58.6            |                  | -54.7            |                  |                  |                 |                 |                   |                  |                  | 4.84             | 3.57             |
| Chlorine (mg/L)                        | 16               |                  | 14               | 9                | 9                | 12              | 11              | 9                 | 11               | 8                | 11               | 11               |
| Conductivity (umhos)                   | 1200             |                  | 1100             | 1290             | 1400             | 1275            | 1300            | 1280              | 1300             | 1310             | 1280             | 1275             |
| hardness (mg/L)                        | 284              |                  | 304              | 298              | 248              | 262             | 264             | 268               | 268              | 274              | 266              | 276              |
| Iron (mg/L)                            | 1.61             |                  | 1.38             | 4.3              | 8.1              | 1.18            | 0.6             | 2.3               | 1.6              | 1.65             | 1.8              | 1.62             |
| Lead (mg/L)                            | <0.05            |                  | <0.05            | <0.005           | 0.027            | <0.005          | <0.005          | 0.008             | <0.005           | <0.005           | <0.005           | <0.005           |
| Magnesium (mg/L)                       | 29               |                  | 29               | 34               | 23               | 25              | 28              | 26                | 27               | 24               | 26               | 25               |
| Manganese (mg/L)                       | 0.13             |                  | 0.09             | 0.14             | 0.45             | 0.08            | 0.09            | 0.13              | 0.15             | 0.1              | 0.09             | 0.1              |
| Nitrogen (mg/L)                        | 0.78             |                  | 0.24             | <0.1             | 0.69             | <0.1            | <0.1            | 0.52              | 0.11             | <0.1             | 0.94             | 0.28             |
| pH                                     | 8.1              |                  | 8.1              | 7.69             | 7.79             | 7.94            | 7.86            | 7.5               | 7.48             | 7.55             | 7.75             | 7.63             |
| Phosphate (mg/L)                       | <0.01            |                  | <0.01            | <0.03            | 0.06             | 0.09            | 0.03            | 0.03              | <0.03            | 0.03             | 0.03             | <0.03            |
| Potassium (mg/L)                       | 15               |                  | 14               | 14               | 16.2             | 15              | 11              | 16                | 15               | 15               | 15               | 15               |
| Radium 226 (pCi/L)                     |                  | 2.1              |                  |                  |                  |                 | 2.01            |                   | 2.98             | 2.37             |                  | 1                |
| Selenium (mg/L)                        | <0.01            |                  | <0.01            |                  |                  |                 |                 |                   |                  |                  | 199              |                  |
| Silicon (mg/L)                         | 6.4              |                  | 6.6              | 2.4              | 7.8              | 6.6             | 10.7            | 7.5               | <2               | 7.1              | 7.4              | 7.85             |
| Sodium (mg/L)                          | 216              |                  | 169              | 164              | 185              | 191             | 195             | 162               | 184              | 207              | 199              | 205              |
| Sulfate (mg/L)                         | 568              |                  | 480              | 404              | 464              | 480             | 468             | 500               | 472              | 492              | 456              | 480              |
| Total Dissolved Solids (mg/L)          | 1006             |                  | 882              | 950              | 936              | 854             | 912             | 862               | 836              | 842              | 792              | 876              |
| Total Suspended Solids (mg/L)          | 0.4              |                  | 1.6              | 11               | 71               | 4               | 3               | 2                 | 2                | 1                | 1                | 6                |
| Uranium (ug/L)                         |                  |                  |                  |                  |                  |                 | 0.004           |                   | 0.6              | 2.5              |                  | 1                |
| Vanadium (mg/L)                        | <0.05            |                  | <0.05            |                  |                  |                 |                 |                   |                  |                  |                  |                  |
| Zinc (mg/L)                            | <0.01            |                  | <0.01            | 0.03             | 0.3              | <0.01           | <0.01           | <0.01             | 0.13             | <0.01            | <0.03            | <0.005           |



**Table C-5. Historic Water-Quality Data From Well #16**

| Analyte                                | 7/22/1981 | 10/19/1981 | 4/12/1982 |
|--|-----------|------------|-----------|
| Alkalinity (mg/L)                      | 157       | 156        | 144       |
| Arsenic (mg/L)                         | 0.005     | <0.005     | <0.005    |
| Bicarbonate as HCO <sub>3</sub> (mg/L) | 157       | 156        | 144       |
| Boron (mg/L)                           |           |            |           |
| Calcium (mg/L)                         | 130       | 130        | 128       |
| Carbonate (mg/L)                       |           |            |           |
| Cation/Anion Balance (%)               |           |            |           |
| Chlorine (mg/L)                        | 7         | 7          | 6         |
| Conductivity (umhos)                   | 1150      | 1160       | 1175      |
| hardness (mg/L)                        | 540       | 520        | 528       |
| Iron (mg/L)                            | 0.25      | 0.12       | 0.05      |
| Lead (mg/L)                            | <0.005    | 0.015      | <0.005    |
| Magnesium (mg/L)                       | 55        | 51         | 54        |
| Manganese (mg/L)                       | 0.15      | 0.17       | 0.17      |
| Nitrogen (mg/L)                        | <0.1      | 0.28       | 0.22      |
| pH                                     | 7.32      | 7.31       | 7.39      |
| Phosphate (mg/L)                       | <0.03     | 0.03       | <0.03     |
| Potassium (mg/L)                       | 28        | 24         | 21        |
| Radium 226 (pCi/L)                     | 4.9       |            | 5.38      |
| Selenium (mg/L)                        |           |            |           |
| Silicon (mg/L)                         | 14.27     | 7.5        | <2        |
| Sodium (mg/L)                          | 55        | 45         | 50        |
| Sulfate (mg/L)                         | 510       | 494        | 488       |
| Total Dissolved Solids (mg/L)          | 894       | 796        | 848       |
| Total Suspended Solids (mg/L)          | 1         | 1          | <1        |
| Uranium (ug/L)                         | 0.007     |            | 1.7       |
| Vanadium (mg/L)                        |           |            |           |
| Zinc (mg/L)                            | <0.01     | 0.05       | 0.07      |

**Table C-6. Historic Water-Quality Data From Well #18**

| <b>Analyte</b>                         | <b>8/6/1979</b> | <b>8/15/1979</b> | <b>9/12/1979</b> | <b>10/9/1980</b> | <b>1/8/1981</b> | <b>4/8/1981</b> | <b>7/1/1981</b> | <b>10/1/1981</b> | <b>4/13/1982</b> | <b>7/27/1982</b> | <b>4/11/1983</b> | <b>4/17/1984</b> |
|--|-----------------|------------------|------------------|------------------|-----------------|-----------------|-----------------|------------------|------------------|------------------|------------------|------------------|
| Alkalinity (mg/L)                      | 200             |                  | 238              | 202              | 180             | 192             | 195             | 184              | 190              | 214              | 184              | 182              |
| Arsenic (mg/L)                         | <0.01           |                  | <0.01            | <0.005           | <0.005          | <0.005          | <0.005          | <0.005           | 0.018            | <0.005           | <0.005           | <0.005           |
| Bicarbonate as HCO <sub>3</sub> (mg/L) | 195             |                  | 168              | 202              | 180             | 162             | 195             | 184              | 190              | 214              | 184              | 182              |
| Boron (mg/L)                           | <1              |                  | <1               |                  |                 |                 |                 |                  |                  |                  |                  |                  |
| Calcium (mg/L)                         | 37              |                  | 39               | 35               | 44              | 53              | 38              | 38               | 19               | 40               | 38               | 37               |
| Carbonate (mg/L)                       | 24              |                  | 60               |                  |                 | 30              |                 |                  |                  |                  |                  |                  |
| Cation/Anion Balance (%)               | -75.4           |                  | -75.9            |                  |                 |                 |                 |                  |                  |                  | 2.69             | 2.47             |
| Chlorine (mg/L)                        | 14              |                  | 20               | 13               | 13              | 12              | 11              | 12               | 12               | 8                | 12               | 13               |
| Conductivity (umhos)                   | 1325            |                  | 1300             | 1420             | 1370            | 1375            | 1410            | 1350             | 1400             | 1390             | 1420             | 1410             |
| hardness (mg/L)                        | 142             |                  | 139              | 136              | 136             | 138             | 140             | 140              | 124              | 141              | 140              | 135              |
| Iron (mg/L)                            | 7.42            |                  | 1.25             | 1.4              | 2.1             | 1.34            | 1.9             | 1.4              | 1.3              | 2.6              | 2.6              | 1.45             |
| Lead (mg/L)                            | <0.05           |                  | <0.05            | <0.005           | <0.005          | <0.005          | <0.005          | <0.005           | <0.005           | <0.005           | <0.005           | <0.005           |
| Magnesium (mg/L)                       | 12              |                  | 10               | 15.5             | 12              | 13              | 14              | 13               | 7                | 12               | 14               | 13               |
| Manganese (mg/L)                       | 0.15            |                  | 0.05             | 0.08             | 0.16            | 0.07            | 0.07            | 0.06             | 0.12             | 0.08             | 0.08             | 0.08             |
| Nitrogen (mg/L)                        | 0.87            |                  | 0.28             | 0.34             | 0.35            | 0.39            | 0.25            | 1.4              | 0.36             | <0.1             | 1.04             | 0.42             |
| pH                                     | 8.4             |                  | 8.3              | 7.88             | 7.98            | 8.02            | 7.82            | 7.77             | 7.81             | 7.69             | 7.89             | 7.75             |
| Phosphate (mg/L)                       | <0.01           |                  | <0.01            | <0.03            | <0.03           | <0.03           | 0.03            | 0.03             | 0.033            | 0.03             | 0.04             | <0.03            |
| Potassium (mg/L)                       | 10              |                  | 11               | 9                | 9.4             | 10              | 9               | 12               | 10               | 9                | 10               | 9                |
| Radium 226 (pCi/L)                     |                 | 0.96             |                  |                  |                 |                 | 1.87            |                  | 4.44             | 1.26             |                  | 2.2              |
| Radium 226 (pCi/L)                     |                 |                  |                  |                  |                 |                 |                 |                  |                  | 0.57             |                  |                  |
| Selenium (mg/L)                        | <0.01           |                  | <0.01            |                  |                 |                 |                 |                  |                  |                  | 279              |                  |
| Silicon (mg/L)                         | 6.4             |                  | 5.6              | 3                | <1              | 7.4             | 2.14            | 6.4              | <2               | 7.9              | 7.4              | 7.85             |
| Sodium (mg/L)                          | 281             |                  | 325              | 287              | 263             | 266             | 280             | 252              | 137              | 287              | 279              | 280              |
| Sulfate (mg/L)                         | 525             |                  | 570              | 538              | 504             | 468             | 520             | 510              | 520              | 530              | 506              | 506              |
| Total Dissolved Solids (mg/L)          | 999             |                  | 1118             | 926              | 948             | 974             | 898             | 876              | 906              | 922              | 908              | 520              |
| Total Suspended Solids (mg/L)          | 3.6             |                  | 0.4              | 1                | 3               | 4               | 4               | 2                | 2                | 2                | 1                | 5                |
| Uranium (ug/L)                         |                 | 8                |                  |                  |                 |                 | 0.008           |                  | 7.6              | 6.7              |                  | 8                |
| Vanadium (mg/L)                        | <0.05           |                  | <0.05            |                  |                 |                 |                 |                  |                  |                  |                  |                  |
| Zinc (mg/L)                            | 0.01            |                  | <0.01            | <0.005           | <0.01           | <0.01           | 0.03            | <0.01            | <0.03            | <0.01            | <0.03            | <0.005           |

**Table C-7. Historic Water-Quality Data From Well #42**

| Analyte                                | 8/6/1979 | 8/15/1979 | 9/12/1979 | 10/9/1980 | 1/8/1981 | 4/8/1981 | 7/22/1981 | 10/21/1981 | 4/13/1982 | 7/27/1982 | 4/11/1983 |
|--|----------|-----------|-----------|-----------|----------|----------|-----------|------------|-----------|-----------|-----------|
| Alkalinity (mg/L)                      | 180      |           | 180       | 198       | 188      | 189      | 192       | 179        | 186       | 204       | 188       |
| Arsenic (mg/L)                         | <0.01    |           | <0.01     | <0.005    | <0.005   | <0.005   | <0.005    | <0.005     | 0.025     | <0.005    | <0.005    |
| Bicarbonate as HCO <sub>3</sub> (mg/L) | 171      |           | 195       | 198       | 188      | 165      | 192       | 179        | 186       | 204       | 188       |
| Boron (mg/L)                           | <1       |           | <1        |           |          |          |           |            |           |           |           |
| Calcium (mg/L)                         | 47       |           | 49        | 39        | 48       | 54       | 38        | 39         | 36        | 42        | 37        |
| Carbonate (mg/L)                       | 24       |           | 12        |           |          | 24       |           |            |           |           |           |
| Cation/Anion Balance (%)               | -75.1    |           | -75.8     |           |          |          |           |            |           |           | 0.33      |
| Chlorine (mg/L)                        | 14       |           | 14        | 12        | 9        | 11       | 12        | 11         | 12        | 10.5      | 12        |
| Conductivity (umhos)                   | 1250     |           | 1200      | 1400      | 1360     | 1380     | 1400      | 1365       | 1400      | 1375      | 1400      |
| hardness (mg/L)                        | 138      |           | 147       | 142       | 140      | 142      | 144       | 140        | 148       | 146       | 164       |
| Iron (mg/L)                            | 0.61     |           | 0.63      | 0.25      | 1.5      | 0.42     | 0.55      | 0.4        | 0.5       | 0.84      | 0.38      |
| Lead (mg/L)                            | <0.05    |           | <0.05     | 0.026     | <0.005   | <0.005   | <0.005    | 0.01       | <0.005    | <0.005    | <0.005    |
| Magnesium (mg/L)                       | 5        |           | 6         | 16        | 13       | 13       | 14        | 13         | 13        | 13        | 11        |
| Manganese (mg/L)                       | 0.12     |           | 0.07      | 0.08      | 0.2      | 0.1      | 0.08      | 0.07       | 0.12      | 0.09      | 0.09      |
| Nitrogen (mg/L)                        | 0.52     |           | 0.05      | 0.38      | 0.28     | 0.17     | <0.1      | 0.4        | 0.13      | <0.1      | 0.84      |
| pH                                     | 8.3      |           | 8.4       | 7.86      | 7.96     | 8        | 7.79      | 7.67       | 7.86      | 7.68      | 7.92      |
| Phosphate (mg/L)                       | <0.01    |           | <0.01     | <0.03     | <0.03    | <0.03    | <0.03     | 0.03       | <0.03     | 0.03      | <0.03     |
| Potassium (mg/L)                       | 10       |           | 10        | 10        | 9.4      | 10       | 9         | 12         | 10        | 10        | 10        |
| Radium 226 (pCi/L)                     |          | 51        |           |           |          |          | 37.4      |            | 82.62     | 80.33     |           |
| Selenium (mg/L)                        | <0.01    |           | <0.01     |           |          |          |           |            |           |           | 276       |
| Silicon (mg/L)                         | 6.4      |           | 5.8       | 3         | 1.7      | 6.6      | 4.81      | 7.5        | <2        | 7.9       | 8         |
| Sodium (mg/L)                          | 274      |           | 286       | 282       | 260      | 266      | 280       | 252        | 264       | 283       | 276       |
| Sulfate (mg/L)                         | 525      |           | 560       | 576       | 504      | 498      | 520       | 520        | 520       | 514       | 516       |
| Total Dissolved Solids (mg/L)          | 984      |           | 1033      | 920       | 964      | 964      | 910       | 906        | 903       | 916       | 888       |
| Total Suspended Solids (mg/L)          | 4.8      |           | 5.2       |           | 2        | 8        | 2         | 1          | <1        | <1        | <1        |
| Uranium (ug/L)                         |          | 7         |           |           |          |          | 0.02      |            | 13.6      | 12        |           |
| Vanadium (mg/L)                        | <0.05    |           | <0.05     |           |          |          |           |            |           |           |           |
| Zinc (mg/L)                            | 0.01     |           | <0.01     | 0.01      | <0.01    | <0.01    | 0.01      | 0.01       | <0.03     | <0.01     | <0.03     |



**Table C-8. Historic Water-Quality Data From Well #4002**

| Analyte                                | 9/12/1979 | 4/12/1982 | 7/26/1982 | 7/27/1982 | 4/11/1983 | 4/17/1984 |
|--|-----------|-----------|-----------|-----------|-----------|-----------|
| Alkalinity (mg/L)                      | 150       | 144       | 202       |           | 146       | 146       |
| Arsenic (mg/L)                         | <0.01     | <0.005    | <0.005    |           | <0.005    | <0.005    |
| Bicarbonate as HCO <sub>3</sub> (mg/L) | 134       | 144       | 202       |           | 146       | 146       |
| Boron (mg/L)                           | <1        |           |           |           |           |           |
| Calcium (mg/L)                         | 45        | 46        | 23        |           | 45        | 46        |
| Carbonate (mg/L)                       | 24        |           |           |           |           |           |
| Cation/Anion Balance (%)               | -62.2     |           |           |           | 0.99      | 0.12      |
| Chlorine (mg/L)                        | 8         | 5         | 3         |           | 6         | 7         |
| Conductivity (umhos)                   | 1100      | 1195      | 1160      |           | 1160      | 1190      |
| hardness (mg/L)                        | 187       | 90        | 168       |           | 168       | 184       |
| Iron (mg/L)                            | 2.3       | 2.6       | 1.38      |           | 8.3       | 3.35      |
| Lead (mg/L)                            | <0.05     | <0.005    | <0.005    |           | <0.005    | 0.005     |
| Magnesium (mg/L)                       | 18        | 16        | 10        |           | 13        | 15        |
| Manganese (mg/L)                       | 0.06      | 0.14      | 0.1       |           | 0.09      | 0.1       |
| Nitrogen (mg/L)                        | 0.46      | 0.17      | <0.1      |           | 0.67      | 0.91      |
| pH                                     | 8.5       | 7.52      | 7.51      |           | 7.6       | 7.61      |
| Phosphate (mg/L)                       | <0.01     | 0.033     | <0.03     |           | 0.03      | <0.03     |
| Potassium (mg/L)                       | 13        | 10        | 9         |           | 9         | 9         |
| Radium 226 (pCi/L)                     |           | 43.36     | 32.13     | 32.13     |           |           |
| Selenium (mg/L)                        | <0.01     |           |           |           | 212       |           |
| Silicon (mg/L)                         | 5.1       | <2        | 3.4       |           | 8         | 7.23      |
| Sodium (mg/L)                          | 191       | 198       | 226       |           | 212       | 197       |
| Sulfate (mg/L)                         | 440       | 448       | 427       |           | 450       | 440       |
| Total Dissolved Solids (mg/L)          | 805       | 766       | 770       |           | 740       | 784       |
| Total Suspended Solids (mg/L)          | 1.6       | 6         | 2         |           | 5         | 9         |
| Uranium (ug/L)                         |           | 2.1       | 5         | 5         |           |           |
| Vanadium (mg/L)                        | <0.05     |           |           |           |           |           |
| Zinc (mg/L)                            | 0.01      | <0.03     | <0.01     |           | <0.03     | <0.005    |

**Table C-9. Historic Water-Quality Data From Well #7002**

| <b>Analyte</b>                         | <b>6/15/1979</b> | <b>9/12/1979</b> | <b>10/6/1980</b> | <b>1/6/1981</b> | <b>4/6/1981</b> | <b>7/6/1981</b> | <b>10/19/1981</b> | <b>4/12/1982</b> | <b>7/26/1982</b> | <b>4/11/1983</b> | <b>4/17/1984</b> |
|--|------------------|------------------|------------------|-----------------|-----------------|-----------------|-------------------|------------------|------------------|------------------|------------------|
| Alkalinity (mg/L)                      | 210              | 224              | 269              | 264             | 264             | 263             | 280               | 264              | 300              | 268              | 267              |
| Arsenic (mg/L)                         | <0.01            | <0.01            | <0.005           | <0.005          | <0.005          | <0.005          | <0.005            | <0.005           | 0.011            | <0.005           | <0.005           |
| Bicarbonate as HCO <sub>3</sub> (mg/L) | 256              | 273              | 269              | 264             | 264             | 263             | 280               | 264              | 300              | 268              | 267              |
| Boron (mg/L)                           | <1               | <1               |                  |                 |                 |                 |                   |                  |                  |                  |                  |
| Calcium (mg/L)                         | 194              | 233              | 235              | 337             | 375             | 238             | 230               | 243              | 238              | 242              | 243              |
| Carbonate (mg/L)                       |                  |                  |                  |                 |                 |                 |                   |                  |                  |                  |                  |
| Cation/Anion Balance (%)               | -37.9            | -39.3            |                  |                 |                 |                 |                   |                  |                  | 0.55             | 3.52             |
| Chlorine (mg/L)                        | 16               | 16               | 6                | 9               | 10              | 9               | 8                 | 9                | 6                | 9                | 10               |
| Conductivity (umhos)                   | 1925             | 2000             | 2500             | 2400            | 2400            | 2400            | 2400              | 2400             | 2400             | 2400             | 2500             |
| hardness (mg/L)                        | 1002             | 948              | 990              | 904             | 968             | 956             | 928               | 944              | 970              | 1020             | 928              |
| Iron (mg/L)                            | 3.56             | 2.48             | 2.5              | 3.38            | 2.55            | 2.1             | 2.7               | 2.5              | 2.47             | 5.8              | 2.16             |
| Lead (mg/L)                            | <0.05            | <0.05            | <0.005           | <0.005          | <0.005          | 0.005           | <0.005            | <0.005           | <0.005           | <0.005           | <0.005           |
| Magnesium (mg/L)                       | 126              | 89               | 95               | 72              | 96              | 100             | 93                | 98               | 90               | 90               | 109              |
| Manganese (mg/L)                       | 0.46             | 0.32             | 0.38             | 0.82            | 0.37            | 0.3             | 0.38              | 0.51             | 0.37             | 0.39             | 0.33             |
| Nitrogen (mg/L)                        | 1.6              | 0.29             | <0.1             | 0.16            | 0.52            | <0.1            | 1.01              | 0.15             | <0.1             | 0.44             | 0.37             |
| pH                                     | 7.8              | 8                | 7.27             | 7.33            | 7.59            | 7.63            | 7.14              | 7.21             | 7.26             | 7.3              | 7.26             |
| Phosphate (mg/L)                       | <0.01            | <0.01            | 0.03             | <0.03           | <0.03           | 0.03            | 0.03              | 0.045            | <0.03            | 0.04             | <0.03            |
| Potassium (mg/L)                       | 25               | 25               | 32               | 33              | 35              | 24              | 33                | 29               | 30               | 32               | 27               |
| Radium 226 (pCi/L)                     |                  |                  |                  |                 |                 |                 |                   | 8.69             | 9.37             |                  |                  |
| Selenium (mg/L)                        | <0.01            | <0.01            |                  |                 |                 |                 |                   |                  |                  | 200              |                  |
| Silicon (mg/L)                         | 7.3              | 7.3              | 4.17             | <1              | 7.4             | 8.83            | 8.6               | <2               | 8.6              | 8.7              | 8.45             |
| Sodium (mg/L)                          | 181              | 191              | 172              | 181             | 193             | 201             | 180               | 210              | 195              | 200              | 192              |
| Sulfate (mg/L)                         | 1150             | 1105             | 800              | 973             | 1097            | 1107            | 987               | 973              | 1090             | 1107             | 1077             |
| Total Dissolved Solids (mg/L)          | 1818             | 1793             | 1940             | 1822            | 1942            | 1970            | 1690              | 1780             | 1886             | 1820             | 1810             |
| Total Suspended Solids (mg/L)          | 4                | 7.2              | 8                | 4               | 6               | 4               | 6                 | 5                | 2                | 6                | 10               |
| Uranium (ug/L)                         |                  |                  |                  |                 |                 |                 |                   | 0.2              | 2                |                  | 10               |
| Vanadium (mg/L)                        | <0.05            | <0.05            |                  |                 |                 |                 |                   |                  |                  |                  |                  |
| Zinc (mg/L)                            | <0.01            | <0.01            | 0.005            | <0.01           | <0.01           | <0.01           | <0.01             | <0.03            | <0.01            | <0.03            | <0.005           |

## **APPENDIX 2.7-K**

### **TVA Pump Tests (Boggs, 1983 and Boggs & Jenkins, 1980)**





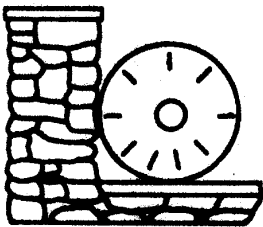
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*KEITH ANDERSON*

WR28-1-520-109

**ANALYSIS OF AQUIFER TESTS CONDUCTED  
AT THE PROPOSED BURDOCK URANIUM MINE SITE  
BURDOCK, SOUTH DAKOTA**



TENNESSEE VALLEY AUTHORITY  
OFFICE OF NATURAL RESOURCES  
DIVISION OF WATER RESOURCES  
WATER SYSTEMS DEVELOPMENT BRANCH  
NORRIS, TENNESSEE

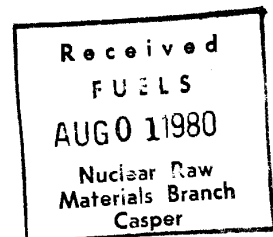
Tennessee Valley Authority  
Office of Natural Resources  
Division of Water Resources  
Water Systems Development Branch

ANALYSIS OF AQUIFER TESTS CONDUCTED  
AT THE PROPOSED BURDOCK URANIUM MINE SITE  
BURDOCK, SOUTH DAKOTA

Report No. WR28-1-520-109

Prepared by  
J. M. Boggs  
and  
A. M. Jenkins

Norris, Tennessee  
May 1980



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## ABSTRACT

Separate aquifer tests were conducted in two aquifers which may be affected by TVA's proposed uranium mining operation near Burdock, South Dakota. In April 1979, a constant-discharge test was conducted in the Chilson member of the Lakota formation which comprises the principal ore body and an aquifer of regional importance. The hydraulic properties of both the Lakota (Chilson) aquifer and the overlying Fuson shale aquitard were determined. A second test was conducted in July 1979 in the Fall River aquifer which overlies the Fuson. The hydraulic characteristics of the Fall River aquifer and a second estimate of the Fuson aquitard properties were obtained from the test. The test results indicate that the two aquifers are hydrologically connected via (1) general leakage through the Fuson shale, and (2) direct pathways, probably in the form of numerous old (pre-TVA) unplugged exploration boreholes.

The hydraulic properties of the Fall River, Fuson and Lakota units obtained from the aquifer test analyses were incorporated into a computer model of the site geohydrologic system. These parameters were refined in a calibration process until the model could reproduce the drawdown responses observed during the Lakota aquifer test. Results indicate the transmissivity and storativity of the Lakota (Chilson) aquifer are approximately 1400 gallons per day per foot (gpd/ft) and  $1.0 \times 10^{-4}$ , respectively. The Fall River aquifer has an estimated transmissivity of 400 gpd/ft and a storativity of about  $1.4 \times 10^{-5}$ . The hydraulic conductivity of the Fuson aquitard is estimated at approximately  $10^{-3}$  foot per day. The specific storativity of the Fuson was not measured but is assumed to be about  $10^{-6}$  feet<sup>-1</sup>.

## INTRODUCTION

This report describes the aquifer testing program conducted at the proposed uranium mine site in Burdock, South Dakota. The purpose of the program was to determine the hydrogeologic conditions in the mining area in order to predict mine dewatering requirements and impacts.

The Fall River formation and the Chilson member of the Lakota formation comprise the principal aquifers in the vicinity of the proposed mine. These aquifers are separated by the Fuson shale member of the Lakota formation which acts as an aquitard. The uranium deposits to be mined lie within the Chilson unit.

Two unsuccessful aquifer tests were conducted at the site prior to those described in this report. The first test was conducted at the Burdock test well in February 1977. Pumping took place from both the Fall River and Lakota aquifers during the 14-day test. The test results were invalidated by questionable well discharge measurements and by mechanical difficulties with a deep-well current meter used to measure the quantity of water pumped from each aquifer. A second test lasting three days was performed in November 1977. Pumping was restricted to the Lakota aquifer during the test in order to determine the potential for leakage through the Fuson shale from the overlying Fall River aquifer. The results of the test were inconclusive because (1) five observation wells used in the test were subsequently found to be improperly constructed and (2) pressure gauges used to monitor pumping response at several wells malfunctioned during the test.

The problems associated with the two earlier tests were corrected for the tests described in this report. The defective observation wells were pressure sealed with cement grout and replaced with properly constructed wells. More reliable instrumentation for monitoring potentiometric heads in observation wells was used in subsequent tests.

## HYDROGEOLOGY

### Regional Setting


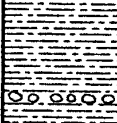


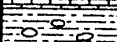




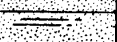
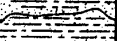
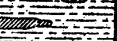

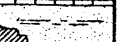

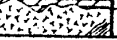

The proposed mine site is located in the northwestern corner of Fall River County, South Dakota, less than one mile southeast of the community of Burdock. Geologically, the site is situated on the southwest flank of the Black Hills Uplift (see Appendix, Figure 1). The stratigraphy of the region consists of a sequence of rocks ranging in age from Precambrian to Recent which crop out peripherally to the Black Hills. The Precambrian rocks crop out near the center of the Black Hills, and progressively younger rocks crop out to the southwest. Surficial rocks in the site area range in age from lower Cretaceous to Recent. A generalized stratigraphic column for the site is shown in Table 1.

The major structural features of the region are the southwesterly-trending Dewey and Long Mountain structural zones. Faults, fractures and breccia pipes in these zones are believed to affect the ground-water regime.

### Aquifers

The principal aquifers in the region are the alluvial deposits associated with the Cheyenne River and its major tributaries, the Fall River formation, the Lakota formation, the Sundance formation, and the Pahasapa (or Madison) formation. Except for the alluvium, these aquifers crop out peripherally to the Black Hills where they receive recharge from precipitation. Ground-water movement is in the direction of dip, radially from the central Black Hills. In most instances, ground water in these aquifers is under artesian conditions away from the

**TABLE 1: GENERALIZED STRATIGRAPHIC COLUMN FOR SITE REGION  
(FROM KEENE, 1973)**

| PERIOD        | FORMATION NAME   | SYM-BOL | COLUMN  | LITHOLOGIC DESCRIPTION  | THKNS. IN FEET  | HYDROLOGIC CHARACTERISTICS  |
|---------------|--|---------|---|---|---|---|
| Quaternary    | Alluvium   | Qal     |    | Gravel, sand, and silt floodplain deposits. Alluvial terraces and windblown material.   | 1-30  | Good to excellent aquifer along floodplains; terraces generally non-productive except for scattered springs.  |
|               | Pierre Fm.   | Kp      |    | Dark gray shale, weathering brown or buff and containing many fossiliferous concretions.<br><br>Scattered concretions which form "tepee buttes"                               | 1000+   | Relatively no value as an aquifer; locally large diameter wells in stream valleys may yield small amounts of highly mineralized water during wet seasons. |
| Cretaceous    | Niobrara Fm.   | Kn      |    | Black fissile shale, cone-in-cone concretions.<br>Gray calcareous shale, weathering yellow and impure chalk with <i>Ostrea Congesta</i> .                                     | 100-225   | No known wells.   |
|               | Turner sand  | Kcr     |    | Light gray shale with large concretions.  | 520-540   | Relatively impermeable; possible small yields from Turner and Wall Creek sands.   |
|               | Wall Creek sand  |         |   | Gray shale with thin sandstone layers.  |   |   |
|               | Greenhorn Lms.   | Kg      |    | Thin bedded hard limestone, weathering creamy white, contains <i>Inoceramus labatus</i> .   | 50  | Too thin and dense to be an aquifer.  |
|               | Belle Fourche Fm.  | Kgs     |    | Light gray shale, bentonite, large concretions.   | 870   | Newcastle sand may yield water, permeability is variable.   |
|               | Mowry Shale  |         |   | Light gray siliceous shale.   |   |   |
|               | Graneros Group<br>Newcastle sand   |         |   | Thin brown-to-yellow sandstone.   |   |   |
|               | Skull Creek Shale  |         |   | Black shale   |   |   |
|               | Fall River Fm.   | Kfr     |    | Interbedded red-brown massive sandstone and Carbonaceous shales.  | 30-165  | Largest producer in the area. Yields up to 60 gpm of highly mineralized water (flow). Water quality generally poor, sometimes yields hydrogen sulfide.    |
|               | Fuson Shale<br>Minnewasta Lms.   | Kik     |   | Gray-to-purple shale, thin shales.<br>Light gray massive limestone.   | 0-180<br>0-25   |   |
| Lakota Fm.    | Coarse, hard, cross-bedded sandstone, buff-to-gray, coal beds locally near base. |         |   | 130-230   | Relatively good aquifer from the lower Chisnon member, up to 30 gpm artesian flow |   |
| Jurassic      | Morrison Fm.   | Km      |  | Green-to-maraan shale, thin sandstone.  | 0-125   | No known wells, possible aquifer.   |
|               | Unkpapa Fm.  | Ju      |  | Fine grained, massive, vari-colored sandstone.  | 0-240   | No known wells, possible aquifer.   |
|               | Sundance Fm.   | Jsd     |  | Alternating beds of red sandstone and red-to-green marine shales.   | 250-450   | Produces small amounts of water from the sands suitable for domestic use.   |
| Triassic      | Speartfish Fm.   | Rs      |  | Red silty shale, limestone, and anhydrite near the top.<br>Redbeds.<br>Gypsum locally near the base.  | 400   | Poor producer, small yields of sulfate water  |
| ?             | Minnekahta Lms.  | Cmk     |  | Pale brown, to gray dense, crystalline limestone.   | 50  | Locally secondary fracture porosity   |
| Permian       | Opeche Fm.   | Co      |  | Red thinly bedded sandstones and shales, purple shale near top.   | 100   | No known wells  |
| ?             | Minnelusa Fm.  | Cml     |  | Converse sand, red-to-yellow cross bedded sand. Red marker, thin red shale near middle. Leo sands, series of thin limestones.<br>Dolomite at bottom with basal laterite zone. | 755-1040  | Permeability variable; tremendous flows of warm mineralized water recorded near the periphery of the Black Hills. Excellent potential.                    |
| Pennsylvanian |  |         |   |   |   |   |
| Mississippian | Pahasapa Fm.   | Cps     |  | Massive, light colored dolomite and limestone, cavernous in upper 100 feet  | 165-465   | Most promising aquifer in the area. The 2 wells in this aquifer produce large amounts of water suitable for domestic use                                  |
| Precambrian   | Metamorphic and igneous rocks  | PC      |  | Granite, schists, quartzite, and slates.  | ---   | No potential.   |

outcrop area, and water flows from numerous wells in the area at ground surface.

The Fall River and Lakota formations which form the Inyan Kara Group are the principal aquifers in the region. The alluvium is used locally as a source of domestic and stock water. The Sundance formation is used near its outcrop area in central and northwestern Fall River County. The Pahasapa (Madison) formation is locally accessible only by very deep wells and is the source for five wells in the city of Edgemont.

The Fall River and Lakota aquifers are of primary concern because of the potential impact of mine dewatering on the numerous wells developed in these aquifers in the vicinity of the mine. At the proposed mine site, the Fall River consists of approximately 120 feet of interbedded fine-grained sandstone, siltstone and carbonaceous shale. The Fall River aquifer is overlain by approximately 250 feet of the Mowry and Skull Creek shales unit, which act as confining beds. Twenty-six domestic and stock-watering wells are known to be developed in the Fall River formation within a four-mile radius of the mine site. Many of these are flowing at the surface.

The Fall River formation is underlain by Fuson shale member of the Lakota formation. Thickness of the Fuson is on the order of 60 feet in the site vicinity. The Fuson acts as a leaky aquitard between the Fall River and Lakota aquifers. A physical examination of undisturbed core samples of Fuson indicates that the shale itself has a very low permeability. However, aquifer tests suggest a direct connection through the Fuson which may be the result of some as-yet-unidentified structural features or old unplugged exploration holes.



The Chilson member of the Lakota formation is the second most widely used aquifer in western Fall River County, as the source for some 23 wells within a four-mile radius of the mine site. It is also the uranium-bearing unit to be mined. The Chilson consists of about 120 feet of consolidated to semi-consolidated, fine-grained sandstone and siltstone. It is underlain by the Morrison formation consisting of interbedded shale and fine-grained sandstone. Regionally, the Morrison is not considered an aquifer. Under conditions of groundwater withdrawal from the Chilson, the Morrison is expected to act as an aquitard.

Recharge to the Fall River and Lakota aquifers is believed to occur at their outcrop areas. Bowles (1968) has theorized that recharge to these aquifers may also be derived from the upward movement of ground water along solution collapses and breccia pipes from the deeper Minnelusa and Pahasapa aquifers. The solution collapse and breccia pipe features lie within the Dewey and Long Mountain structural belts.

## AQUIFER TEST DESIGN

The objective of the aquifer testing program was to obtain sufficient quantitative information about local hydrogeologic conditions to enable prediction of mine dewatering requirements and impacts to both the Fall River and Lakota aquifers. Since the two aquifers involved are separated by the Fuson aquitard, two distinct pumping tests were required to obtain the necessary information about each formation: one test in which the Lakota aquifer was pumped, and another in which pumping was limited to the Fall River aquifer. During both tests ground-water levels were monitored in observation wells developed in each of the three formations. Data obtained from these tests were then analyzed to obtain estimates of the hydraulic properties of the aquifers and aquitard.

The Burdock test well was constructed approximately 600 feet north of the proposed mine shaft. Total depth of the well is 559 feet. The well is screened in both the Fall River and Lakota aquifers as shown in Figure 2.

Fifteen observation wells were constructed within an approximate one-mile radius of the pumping well as indicated in Figure 3. Seven of these wells are developed in the Fall River formation, five in the Lakota, and three in the Fuson. In addition, there is a single well developed in the Sundance formation located approximately one mile from the test well. This well was not constructed specifically for the aquifer tests, but was monitored periodically during the Lakota aquifer test. Construction details for these wells are given in Table 2.

TABLE 2. Observation Well Construction Details

| <u>Well No.</u> | <u>Total Depth (feet)</u> | <u>Casing Diameter (inches)</u> | <u>Depth Interval of Open Borehole or Well Screen (feet)</u> | <u>Distance From Pumped Well (feet)</u> |
|-----------------|---------------------------|---------------------------------|--|---|
| B-10LAK         | 550                       | 4                               | 510-550  | 195                                     |
| B-10FU          | 395                       | 4                               | 377-395  | 255                                     |
| B-10FR          | 350                       | 4                               | 300-350  | 177                                     |
| B-1LAK          | 570                       | 4                               | 525-570  | 405                                     |
| B-1FU           | 440                       | 4                               | 420-440  | 350                                     |
| B-1FR           | 376                       | 4                               | 334-376  | 373                                     |
| B-11LAK         | 550                       | 4                               | 504-550  | 618                                     |
| B-11FR          | 360                       | 4                               | 315-360  | 620                                     |
| B-9LAK          | 545                       | 1                               | 503-545  | 1540                                    |
| B-9FR           | 293                       | 1                               | 251-293  | 1540                                    |
| B-7LAK          | 441                       | 1                               | 399-441  | 2507                                    |
| B-7FR           | 252                       | 1                               | 210-252  | 2540                                    |
| Sundance Well   | 880                       | 7 7/8                           | 666-780  | 4763                                    |

Inasmuch as water levels in each hydrogeologic unit will respond differently during pumping tests, it is important that each observation well reflect the potentiometric head in the intended uncased borehole interval. Several observation wells used in previous tests were suspected of leaking along the grout seal placed in the annular space between well casing and borehole wall. As a result, special precautions were taken to ensure proper construction of the observation wells used in the present tests. A geophysical device known as a cement logging probe was used to check the continuity of the cement grout seal in each well after construction. All were found to be properly sealed.

The so-called ratio-method of multiple-aquifer test analysis (Neuman and Witherspoon, 1973) requires that the response of water levels in both the pumped and unpumped aquifers and in the intervening aquitard be monitored during the test. Water level responses in these units must be measured in wells located at approximately the same radial distance from the pumped well. To obtain the necessary data, two groups of observation wells were constructed, each group having one well developed in the Fall River, one in the Fuson, and one in the Lakota (Chilson member). The B-10 group was located approximately 200 feet northeast of the pumping well, while the B-1 group was located approximately 375 feet to the southwest. These well groups were located close to the pumped well to ensure response in the aquitard and in the unpumped aquifer, if such responses were to occur at all. The remaining well groups (B-7, B-9 and B-11 series) contain only Fall River and Lakota wells.

Under natural conditions, the test well and all monitor wells except for those of the B-7 group flow at ground surface if not capped. The two previous tests conducted at the site indicated that observation wells in the pumped aquifer located close to the pumping well would become non-flowing at some point during the test. Thus, pressure sensing devices would be required during the early part of the test and depth measuring techniques during later periods. To ensure adequate data records, each flowing well was equipped with two pressure measuring devices. Malfunctions of several pressure gauges on previous tests pointed out the need for a back-up pressure measuring device.

Three types of pressure sensors were used: mercury manometers, electronic pressure transducers, and mechanical pressure gauges. The B-1 and B-10 observation well groups were equipped with mercury manometers and pressure transducers. As the closest wells to the pumping center, the data from these wells are most important in the multiple aquifer analysis and warrant the best instrumentation. Pressure transducers from all wells were wired to a central terminal and could be monitored frequently during the tests. Each well in groups B-9 and B-11 was equipped with a mercury manometer and a mechanical pressure gauge. Electric probes were used to measure water levels in the non-flowing wells of the B-7 group. These devices were also used to measure water levels in other wells which became non-flowing during pumping tests. Potentiometric head in the pumped well was measured with a mercury manometer, an air line and an electric probe.

## LAKOTA AQUIFER TEST

Several months prior to the Lakota test, a pneumatic packer was set within the Fuson section of the test well to prevent communication between the Fall River and Lakota aquifers through the well. A submersible pump was set below packer to restrict pumping to the Lakota aquifer. Well-head valves on the test well and other artesian observation wells were closed to prevent flow in order to bring the ground-water system into equilibrium before testing.

Hydrographs for the test well and observation wells prior to test are shown in Figures 4 and 5. These hydrographs typify the basic relationship between the potentiometric heads in the Fall River, Fuson and Lakota, i.e., heads are highest in the Lakota, lowest in the Fall River, and at an intermediate position within the Fuson. The irregular readings recorded during January and February 1979 were due to depressurization of the aquifers during the installation of instrumentation and new wells. The pre-test ground-water level configuration in the Lakota aquifer on April 18 is shown in Figure 6.

### Test Procedures and Results

A constant-discharge aquifer test was initiated at 1300 hours on April 18, 1979. Discharge from the well was pumped via pipeline to a stock-watering pond located approximately 0.75 miles from the test well. Pumpage was measured with an in-line flow meter and with an orifice plate and manometer device at the end of the discharge line. The pumping rate varied little during the test ranging from 201 to 205 gpm and averaging 203 gpm. The pumping phase of the test lasted for

73 hours (3.04 days) and was followed by a 30 day period of recovery measurements.

Figure 7 shows a semilogarithmic graph of drawdown (s) versus time (t) for the pumping well (Lakota aquifer). Erratic readings during the first 200 minutes of the test are the result of problems with the airline equipment, and are not due to discharge variations. These difficulties were subsequently corrected, but in general airline measurements are believed to be accurate only to within about  $\pm 2$  feet.

Semilog graphs for the observation well groups are shown in Figures 8 through 12. Note that a slight initial increase in hydrostatic pressure is indicated in the Fall River and Fuson wells of the B-10 and B-1 well groups. This anomalous trend is more pronounced in the Fuson wells than in the Fall River wells and persists for approximately 90 minutes in B-10FU. The response is believed to be due to an increase in pore pressure resulting from deformation of the matrix of these formations.<sup>1</sup> In any case, the anomalous trend was recorded by both the pressure transducers and mercury manometers, and is not the result of measurement error.

The Jacob straight-line method (see Walton, 1970, pp. 130-133) was applied to the semilog graphs for the Lakota wells to obtain the values of transmissivity (T) and storativity (S) presented in Table 3. In the case of the closer observation wells, two straight-line

<sup>1</sup>During the early stages of pumping, water removed from the Lakota in the immediate vicinity of the well causes compaction of the aquifer. This, in turn, may cause the overlying strata to flex slightly in the area where the underlying support of the Lakota has been reduced. The resulting deformation in the overlying formations causes compressive forces which temporarily increase pore pressures in these materials. Subsequently, the effect of pumping-induced depressurization is transmitted through the overlying materials, gradually lowering the hydrostatic pressure.

TABLE 3. Lakota Aquifer Properties

| Well No. | r (ft) | Jacob Method   |                      |                |                      | Theis Method   |                      |                |                      | Recovery Method |                |
|----------|--------|----------------|----------------------|----------------|----------------------|----------------|----------------------|----------------|----------------------|-----------------|----------------|
|          |        | $T_e$ (gpd/ft) | $S_e$ --             | $T_l$ (gpd/ft) | $S_l$ --             | $T_e$ (gpd/ft) | $S_e$ --             | $T_l$ (gpd/ft) | $S_l$ --             | $T_e$ (gpd/ft)  | $T_l$ (gpd/ft) |
| PW-LAK   | 0.67   | 1980           | --                   | 1260           | --                   | --             | --                   | --             | --                   | --              | --             |
| B-10LAK  | 195    | 2680           | $7.6 \times 10^{-5}$ | 1370           | $3.5 \times 10^{-4}$ | 2530           | $8.4 \times 10^{-5}$ | 1660           | $1.6 \times 10^{-4}$ | 2060            | 1300           |
| B-11LAK  | 405    | 2140           | $4.4 \times 10^{-5}$ | 1340           | $1.2 \times 10^{-4}$ | 2120           | $4.8 \times 10^{-5}$ | 1550           | $8.4 \times 10^{-5}$ | 1970            | 1240           |
| B-111LAK | 620    | --             | --                   | --             | --                   | 2530           | $1.1 \times 10^{-4}$ | 1530           | $1.5 \times 10^{-4}$ | --              | 1250           |
| B-9LAK   | 1540   | --             | --                   | --             | --                   | --             | --                   | 1370           | $1.3 \times 10^{-4}$ | --              | 1290           |
| B-7LAK   | 2507   | --             | --                   | --             | --                   | --             | --                   | 1760           | $6.5 \times 10^{-5}$ | --              | 1500           |
| Average: |        | 2270           | $6.0 \times 10^{-5}$ | 1320           | $2.4 \times 10^{-4}$ | 2390           | $8.1 \times 10^{-5}$ | 1570           | $1.2 \times 10^{-4}$ | 2015            | 1270           |

NOTE: Subscript "e" denotes an aquifer parameter determined using early drawdown (or recovery) data. Similarly, subscript "l" denotes a parameter computed from late data.



solutions were possible: one using the early data and another using the late data. Note that data for wells B-7L, B-9L and B-11L cannot be analyzed by the Jacob method because data do not satisfy the criterion that  $r^2S/4Tt \leq 0.01$  (consistent units), where  $r$  is the distance between the pumped well and the observation well.

Logarithmic graphs of drawdown data for all observation wells are given in Figures 13 through 17. Their curve-matching techniques (Walton, 1970, pp. 209-211) were applied to the Lakota curves to obtain  $T$  and  $S$  estimates for the Lakota aquifer. As with the Jacob analyses, two curve-match solutions were possible: one using the early, steeply-rising portions of the  $s$ - $t$  curves, and another using the later data. Both solutions are given in Table 3.

A semilogarithmic graph of distance versus drawdown (Figure 18) was constructed by plotting the final drawdown in each Lakota well versus its radial distance from the pumped well. The Jacob straight-line techniques were applied to these data to obtain  $T$  and  $S$  values for the Lakota of 1780 gpd/ft and  $7.7 \times 10^{-5}$ , respectively. However, this type of analysis is applicable only to nonleaky aquifer systems. Since leakage obviously occurred during the test, the results are considered unreliable.

Contour maps of the final drawdown in the Lakota and Fall River aquifers at the end of the test are shown in Figures 19 and 20, respectively. The drawdown cone in both aquifers is slightly elongated in a northwesterly direction. This is probably an indication of anisotropic transmissivity, with the transmissivity in the direction parallel to the axis of elongation being somewhat greater than that in the direction normal to the axis of elongation. The principal direction of trans-

missivity parallels the strike of a regional fracture-joint set, suggesting a possible explanation for the observed drawdown configuration.

Following the pumping phase of the test, water level recovery measurements were made at all observation wells for a period of 30 days. Attempts were also made to monitor recovery in the pumped well using an airline. However, data collected were highly erratic suggesting a malfunction of the airline equipment. Semilogarithmic graphs of residual drawdown versus  $t/t'$  (ratio of time since pumping started to time since pumping stopped) for the observation wells are shown in Figures 21 through 25. Lakota graphs were analyzed using Jacob straight-line techniques to obtain the estimates of transmissivity presented in Table 3. Again, two straight-line fits are possible for the closer Lakota wells. Both are given in Table 3.

#### Interpretation of Test Results

The drawdown trends recorded in the observation wells indicate some important qualitative information about hydrogeologic conditions at the proposed mine site, in addition to providing a basis for determining hydraulic properties of materials. The relative response of the Fall River, Fuson and Lakota formations as reflected in the B-10 and B-1 groups (Figures 13 and 14), is not typical of the response that would be expected in an ideal leaky multiple aquifer system. Ideally, the  $s-t$  curve for the intervening aquitard lies between the curves for the pumped and unpumped aquifers. That is, in a logarithmic plot of  $s-t$  data the aquitard (Fuson) curve would lie below the curve for the pumped aquifer (Lakota), and above the curve for the unpumped aquifer (Fall River). However, "ideal" trends are not evident in the

observed data until after 300 minutes of pumping in the case of the B-10 group, and not until after 2000 minutes in the case of the B-1 group. The fact that a greater pumping response is observed in Fall River formation than in the Fuson during the early part of the test indicates that direct (though restricted) avenues through the Fuson must exist. This condition was suspected before the test, and is believed to be the result of numerous old, unplugged uranium exploration boreholes in the test site vicinity. The shift to a more ideal relationship among the s-t curves exhibited during the latter part of test possibly indicates that general leakage through the Fuson itself has caught up with leakage through the open boreholes.

The leakage condition which is apparent in the response of the Fuson and Fall River wells is not evident in the Lakota well data. Under ideal conditions, the rate of drawdown in the Lakota observation wells would be expected to gradually decrease and perhaps even level off completely for some period of time. However, the opposite effect is noted in Lakota s-t plots, particularly the semilog graphs for B-10 LAK and B-1 LAK (Figures 8 and 9). The rate of drawdown increases in the latter stages of pumping which might indicate decreasing transmissivity of the Lakota aquifer in the site vicinity. The decrease in transmissivity may be due to aquifer thinning or possibly a facies change to less permeable materials. In any case, it is suspected that the leakage effects in the Lakota drawdown data are masked by the conflicting effect of a decreasing transmissivity in the site vicinity.

In general, the agreement between the Theis and Jacob analyses of s-t data is good. T values computed using early drawdown data average 2390 gpd/ft using the Theis method, and about 2270

gpd/ft using the Jacob method. Early data storativities are also in good agreement averaging  $6.0 \times 10^{-5}$  for the Jacob method and  $8.1 \times 10^{-5}$  for the Theis method. The T values computed from the late data ( $T_{\ell}$ ) are significantly lower than those determined from the early data, whereas late storativities are larger. The Jacob method yields  $T_{\ell}$  values which average 1320 gpd/ft and storativities averaging  $2.4 \times 10^{-4}$ . The Theis method produced an average  $T_{\ell}$  of 1570 gpd/ft and an average  $S_{\ell}$  of  $1.2 \times 10^{-4}$ . The late Theis T values are somewhat higher than the Jacob T's because the Theis method gives some consideration to the earlier data which the Jacob method does not. Transmissivities estimated by the recovery data average 1270 gpd/ft, and are in close agreement with the late Jacob results, although slightly lower.

Ordinarily, in selecting representative T and S for the pumped aquifer in a leaky multiple aquifer system, more emphasis would be placed on the early data collected in the pumped aquifer at the pumped well and closest observation wells. These data are considered least affected by leakage. However, because of the apparent decrease in transmissivity of the Lakota aquifer during the latter stages of the test, it is believed that Lakota parameters computed from the late data are more representative of aquifer properties under a long-term pumping situation such as mine dewatering. On this basis the average transmissivity of the Lakota is estimated to be 1400 gpd/ft and the average storativity  $1.8 \times 10^{-4}$ .

### FALL RIVER AQUIFER TEST

Following completion of recovery measurements associated with the Lakota aquifer test, pumping equipment in the Burdock well was rearranged for the Fall River test. A submersible pump was set within the Fall River section of the well and the pneumatic packer reset below the pump in the Fuson section of the well in order to restrict pumping to the Fall River. A preliminary test of the pump and other equipment lasting less than one hour was conducted on May 29. Unexpectedly, the Fall River aquifer was capable of yielding only about 10 gpm on a sustained basis. Since other Fall River wells in the region yield up to 40 gpm, it was assumed that either the well screen was encrusted or the well was not fully developed, or both. An unsuccessful effort was made to develop the well by pumping. A television camera was subsequently lowered into the well to examine the well screen. Little or no encrustation was observed on the screen. Ultrasonics were used in the well to remove any existing encrustation but the yield of the well was not improved. The low productivity of the well is, therefore, attributed to locally poor water-bearing characteristics of the Fall River formation.

#### Test Procedures and Results

A constant discharge test commenced at 1100 hours on July 24. Water levels in all geologic units were stable prior to the test, as there was no pumping activity in the site vicinity since the completion of well development on July 3. Discharge was measured with an in-line flowmeter, and checked with a 55-gallon container and stopwatch.

During the test the pumping rate varied from 7.6 to 10.4 gpm, and averaged 8.5 gpm. Ground-water levels were monitored in all observation wells shown in Figure 3. The constant discharge test was terminated at 1200 hours on July 26 after 49 hours of pumping. Subsequently, ground-water level recovery measurements were made for a period of six days.

Semilog graphs of drawdown data recorded at the pumped well and observation well groups B-1, B-10 and B-11 are shown in Figures 26 through 29, respectively. No graphs are presented for B-11LAK or the B-7 and B-9 groups as there was no measureable drawdown in these wells. Except for B-11FR, these graphs exhibit a typical straight-line drawdown trend during the first part of the test, followed by a gradual decrease in slope towards the end of the test. This slope change is the result of leakage from adjacent formations, and/or an increase in aquifer transmissivity at some distance from the pumped well. The Jacob method was applied to the semilog graphs to obtain the transmissivity and storativity values shown in Table 4. The  $T_e$  and  $S_e$  values were obtained using early drawdown data recorded during approximately the first 500 minutes of the test.  $T_1$  and  $S_1$  values were computed from data recorded after about 1000 minutes. The only reliable estimates are considered to be those computed for B-1FR and B-10FR. Drawdown data for the pumped well is affected by wellbore storage which is significant in this test because of the relatively low pumping rate. The pumped well drawdown data may also be affected by low well efficiency. The semilog plot for B-11FR cannot be analyzed by the Jacob method because the criterion that  $r^2S/4Tt \leq 0.01$  is not satisfied for any of the data.

TABLE 4. Fall River Aquifer Properties

| Well No. | r (ft) | Jacob Method   |                      |                |          | Theis Method   |                      | Recovery Method |                |
|----------|--------|----------------|----------------------|----------------|----------|----------------|----------------------|-----------------|----------------|
|          |        | $T_e$ (gpd/ft) | $S_e$ --             | $T_l$ (gpd/ft) | $S_l$ -- | $T_e$ (gpd/ft) | $S_e$ --             | $T_e$ (gpd/ft)  | $T_l$ (gpd/ft) |
| PW-FR    | 0.67   | 16.(?)         | --                   | --             | --       | --             | --                   | 11(?)           | --             |
| B-10FR   | 177    | 140.           | $1.8 \times 10^{-5}$ | 410.           | --       | 150.           | $1.7 \times 10^{-5}$ | 80.             | 340.           |
| B-1FR    | 373    | 150.           | $0.8 \times 10^{-5}$ | 420.           | --       | 150.           | $1.1 \times 10^{-5}$ | 90.             | 350.           |
| B-11FR   | 618    | --             | --                   | --             | --       | --             | --                   | --              | --             |
| Average: |        | 145            | $1.3 \times 10^{-5}$ | 415.           | --       | 150.           | $1.4 \times 10^{-5}$ | 85.             | 345.           |

Logarithmic graphs of drawdown data for the pumped well and observations well groups B-10, B-1 and B-11 are presented in Figures 30 through 33, respectively. These curve-matching techniques were applied to the Fall River curves to obtain the aquifer properties given in Table 4.

Semilog recovery curves for the pumped well and well groups B-10, B-1 and B-11 are shown in Figures 34 through 37, respectively. Again, properties computed from the pumped well recovery data are invalidated by well-bore storage effects. Separate estimates of transmissivity obtained from early and late phases of the recovery data are given in Table 4.

#### Interpretation of Fall River Aquifer Test Results

There is good agreement between the early Jacob and Theis results for B-1FR and B-10FR. These analyses indicate an average  $T_e$  of about 150 gpd/ft and an average  $S_e$  of approximately  $1.4 \times 10^{-5}$ . Application of the Jacob method to the late drawdown data yields an average  $T_1$  of 415 gpd/ft. No meaningful storativity values could be computed from the late data. The  $T_e$  values computed by the recovery method are considerably lower than those computed by the other two methods and are believed to be unrealistic. The  $T_1$  values derived from the recovery analyses compare reasonably well with the Jacob late drawdown results.

The computed transmissivity and storativity values are representative of the aquifer only within the relatively small area influenced by the pumping test. The yield of the test well is substantially less than that of several other wells in the region. The difference in well



yields suggests that the Fall River aquifer is less permeable in the mine site vicinity than in certain surrounding areas. The aquifer parameters computed from the early drawdown and recovery data are believed to be representative of the aquifer in the immediate vicinity of the test wells. Parameters obtained from analysis of the late data are probably more representative of regional aquifer characteristics.

### FUSON AQUITARD PROPERTIES

The hydraulic properties of the Fuson aquitard were estimated using an analytical technique known as the "ratio method" developed by Neuman and Witherspoon (1973). The method requires (1) a knowledge of the transmissivity and storativity of the pumped aquifer; (2) draw-down data for the pumped and unpumped aquifers and the aquitard measured in wells located at approximately the same radial distance from the pumped well; and (3) the vertical distance between the aquifer-aquitard boundary and the perforated section of each aquitard well ( $Z$ ). The method yields a value of aquitard hydraulic diffusivity,  $\alpha'$ , equal to  $K'_v/S'_s$ , where  $K'_v$  is the vertical hydraulic conductivity of the aquitard and  $S'_s$  is the specific storativity of the aquitard. To determine  $K'_v$  or  $S'_s$  from  $\alpha'$ , either  $K'_v$  or  $S'_s$  must first be known. In the following analyses a value of  $S'_s = 10^{-6} \text{ ft}^{-1}$  is assumed for the Fuson aquitard. Experience indicates that specific storativities of geologic materials do not vary over as wide a range as do hydraulic conductivities. For this reason, and considering the difficulty and expense of obtaining an accurate measure of  $S'_s$  over the site vicinity, it appears justifiable to assume a value of  $S'_s$  typical of similar geologic materials.

The first step in the analysis is to compute a value of  $s'/s$  at a given radial distance from the pumped well,  $r$ , and at a given time,  $t$ . Next a value of  $t_D$  (dimensionless time for the aquifer equal to  $tT/r^2S$ ) is determined. The values of  $s'/s$  and  $t_D$  are used to compute a value for  $t'_D$  (dimensionless time for the aquitard equal to  $K't/S'_sZ^2$ ) using a family of type curves given in Figure 3 of Neuman and Witherspoon (1973). The vertical hydraulic conductivity of the aquitard  $K'_v$  is then obtained from the following equation:

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$$K'_v = t'_D Z^2 S'_s / t \quad (1)$$

Since separate pumping tests were conducted in the Lakota and Fall River aquifers, it is possible to calculate two independent values of  $K'_v$  for each well group. Fuson aquitard properties computed by the ratio method along with certain pertinent parameters used in the calculations are presented in Table 5.

Note that since the Fall River, Fuson and Lakota observation wells in each well group do not lie at exactly the same radial distance from the pumped well, an average radial distance  $r_{avg}$  is used in the calculations. The  $r_{avg}$  values shown in Table 5 were obtained by averaging the radial distance for the pumped aquifer observation well and the radial distance for the aquitard observation well. Also note that the column labeled "Time Interval" represents the time interval during which  $K'_v$  values were computed. Generally, three or four values of  $K'_v$  were computed at specific times within this interval. These values were then averaged to obtain the  $K'_v$  values shown in Table 5.

The vertical hydraulic conductivity of the Fuson ranges from about  $10^{-4}$  ft/d at the B-1 well group to about  $10^{-3}$  ft/d at the B-10 well group. The agreement between the conductivities computed at each well group site for both tests is good. The reason for the order of magnitude difference between the conductivities at the different well sites is unknown, but may be related to errors caused by differences in the radial distances of observation wells--these differences being somewhat greater for the wells of the B-10 group.

TABLE 5. Fuson Aquitard Properties

| <u>Test</u> | <u>Well Group</u> | <u>r<sub>avg.</sub><br/>(ft)</u> | <u>Z<br/>(ft)</u> | <u>Time Interval<br/>(min.)</u> | <u>(gpd/ft<sup>2</sup>)<sup>K'<sub>v</sub></sup></u> | <u>(ft/d)</u>        |
|-------------|-------------------|----------------------------------|-------------------|---------------------------------|--|----------------------|
| Lakota      | B-10              | 225                              | 28                | 100-393                         | $2.0 \times 10^{-2}$                                 | $2.7 \times 10^{-3}$ |
|             | B-1               | 378                              | 11                | 100-393                         | $1.0 \times 10^{-3}$                                 | $1.3 \times 10^{-4}$ |
| Fall R.     | B-10              | 216                              | 25                | 100-300                         | $4.8 \times 10^{-3}$                                 | $6.6 \times 10^{-4}$ |
|             | B-1               | 362                              | 40                | 1200-2350                       | $1.3 \times 10^{-3}$                                 | $1.8 \times 10^{-4}$ |

The magnitudes of computed conductivities are slightly higher than expected on the basis of the physical characteristics of the Fuson, although they are still within reason. The presence of open boreholes may have caused a more rapid drawdown response in the Fuson monitor wells than would have occurred otherwise. As a result, the calculated  $K'_v$  values are probably larger than the actual conductivity of the Fuson shale. The calculated  $K'_v$  values are, however, probably smaller than the effective  $K'_v$  of the aquitard in the areas where it is breached by open boreholes.

### COMPUTER MODEL SIMULATIONS

The hydraulic properties estimated for the Fall River, Fuson and Lakota formations were incorporated into a computer model of the site geohydrologic system. Simulations of the Lakota aquifer test were performed to see if the model could reproduce the drawdown responses observed during the test. An acceptable match between the measured and computed responses would indicate the validity of the estimated formation properties, and thus enhance the credibility of the model for predicting mine dewatering requirements and impacts.

A finite element numerical model developed by Narasimhan et al. (1978) was used for the aquifer test simulations. The aquifer/well-field system was modeled in three dimensions using axial symmetry. The hydraulic properties of the Fall River, Fuson and Lakota formations obtained from the aquifer test analyses were used as initial input data (see Table 6). Uniform properties were assumed for each hydrogeologic unit. The shale units which lie above the Fall River formation and those which lie below the Lakota were assumed to be impermeable in the model. All simulation comparisons were made for the Lakota aquifer test. The Lakota test stressed a larger portion of the multiple aquifer system than did the Fall River test, and more closely approximates the flow regime expected during mine dewatering.

A comparison of the measured and computed results for the initial simulation run are shown in Figure 38. In general, the agreement between the computed and observed drawdown graphs for the Lakota aquifer are good. However, there are large discrepancies in the Fall River and Fuson responses.

TABLE 6. Parameters Used In Computer Simulations

| Formation        | Initial Parameters |                      |                      |                   |                           | Final Parameters |                      |                      |                 |                           |
|------------------|--------------------|----------------------|----------------------|-------------------|---------------------------|------------------|----------------------|----------------------|-----------------|---------------------------|
|                  | T<br>(gpd/ft)      | S<br>(--)            | $K_v$<br>(ft/d)      | $K_v/K_h$<br>(--) | Ss<br>(ft <sup>-1</sup> ) | T<br>(gpd/ft)    | S<br>--              | $K_v$<br>(ft/d)      | $K_v/K_h$<br>-- | Ss<br>(ft <sup>-1</sup> ) |
| Fall River       | 150.               | $1.4 \times 10^{-5}$ | $5.6 \times 10^{-2}$ | 1/3               | $1.2 \times 10^{-7}$      | 400              | $1.4 \times 10^{-5}$ | $4.6 \times 10^{-2}$ | 1/10            | $1.2 \times 10^{-7}$      |
| Fuson            | 0.13               | $6.0 \times 10^{-5}$ | $1.7 \times 10^{-4}$ | 1/3               | $1.0 \times 10^{-6}$      | 0.45             | $6.0 \times 10^{-5}$ | $1.0 \times 10^{-3}$ | 1/1             | $1.0 \times 10^{-6}$      |
| Lakota (Chilson) | 1400.              | $1.8 \times 10^{-4}$ | $5.0 \times 10^{-1}$ | 1/3               | $1.5 \times 10^{-6}$      | 1400.            | $1.0 \times 10^{-4}$ | $1.5 \times 10^{-1}$ | 1/10            | $8.3 \times 10^{-7}$      |



Several attempts were made to improve the match between the computed and observed drawdown responses by trial-and-error adjustment or calibration of model parameters. The most reliable parameters, such as the computed Lakota and Fall aquifer coefficients, were only slightly altered in the calibration process, whereas the least reliable parameters, including the ratio of vertical to horizontal permeability and the Fuson properties, were allowed to vary over a wider (though reasonable) range. The hydraulic properties within each hydrogeologic unit were assumed to be uniform throughout the calibration process.

The set of hydraulic parameters yielding the best agreement between measured and observed drawdown data is given in Table 6. The final parameter set differs only slightly from the original. The largest changes were made in the  $K_v/K_h$  terms which were unknown to begin with; and in the Fuson hydraulic conductivity which was increased by a factor of five. Both the early and late Fall River T values computed from the aquifer test analyses (150 and 415 gpd/ft, respectively) were tested during model calibration. The drawdown response of the model was found to be relatively insensitive to the value of T used. A transmissivity of 400 gpd/ft is included in the final parameter set as it is believed to be more characteristic of the aquifer regionally.

The match between the measured and computed drawdown responses, shown in Figure 39, is considered acceptable in light of the fact that uniform aquifer-aquitard properties were used in the model. The apparent discrepancies are believed to be due to the heterogeneity and anisotropy of the actual system. The departures which occur during the early phase of the simulation appear large, but are not significant.

The ability of the model to predict the long-term response of system is more important. Thus, more significance is attached to the agreement between the simulated and observed results for the latter part of the test which, in most cases, is quite good. The final set of aquifer-aquitard properties are considered to represent a valid basis for future predictive modeling.

## SUMMARY AND CONCLUSIONS

The aquifer test results indicate that the Fuson member of the Lakota formation is a leaky aquitard separating the Fall River and Lakota aquifers. The hydraulic communication between the two aquifers observed during the tests is believed to be the result of (1) general leakage through the primary pore space and naturally occurring joints and fractures of the Fuson shale, and (2) direct connection of aquifers via numerous old unplugged exploratory boreholes. Whereas, the former leakage mechanism is a regional characteristic of the Fuson, leakage caused by borehole short-circuiting is probably limited to the relatively small area of intensive uranium exploration in the Burdock vicinity.

The Lakota (Chilson) aquifer has an estimated transmissivity of approximately 1400 gpd/ft and a storativity of about  $1.0 \times 10^{-4}$ . These properties are representative of the Lakota in the area affected by the pumping test, and are consistent with what is known or suspected about the aquifer regionally. The transmissivity and storativity of the Fall River aquifer are estimated at approximately 400 gpd/ft and  $1.4 \times 10^{-5}$ , respectively. Test results indicate that the transmissivity of the Fall River may be considerably less than 400 gpd/ft in the immediate vicinity of the test site. However, the selected transmissivity value is more consistent with regional aquifer characteristics.

The hydraulic conductivity of the Fuson aquitard is estimated at approximately  $10^{-3}$  ft/d. The specific storativity of the Fuson was not measured but is assumed to be about  $10^{-6}$  ft<sup>-1</sup>. If open boreholes

are present at the test site as suspected, the computed hydraulic conductivity is probably higher than the true conductivity of the shale, yet lower than the effective conductivity of the aquitard where short-circuited by open boreholes. For this reason, the selected aquitard conductivity of  $10^{-3}$  ft/d should provide a conservative estimate of mine dewatering impacts. Outside of the relatively small area where the aquitard is breached by boreholes, leakage between the two aquifers will be governed by the true conductivity of the shale which is probably on the order of  $10^{-4}$  ft/d or less.

The hydraulic properties of the Fall River, Fuson and Lakota (Chilson) formations computed from aquifer test data were incorporated into a computer model of the site geohydrologic system. These parameters were refined through repeated simulations of the Lakota aquifer test until the model could reproduce the drawdown responses observed during the test. The agreement between the observed and computed responses indicates the validity of the aquifer-aquitard properties, and should enhance the credibility of future predictive models using these parameters.

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2. Keene, J. R., "Ground-water Resources of the Western Half of Fall River County, South Dakota." Rept. of Inv. No. 109, S. D. Geol. Survey, 1973.
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5. Walton, W. C., Groundwater Resource Evaluation, McGraw-Hill, New York, 1970.

APPENDIX

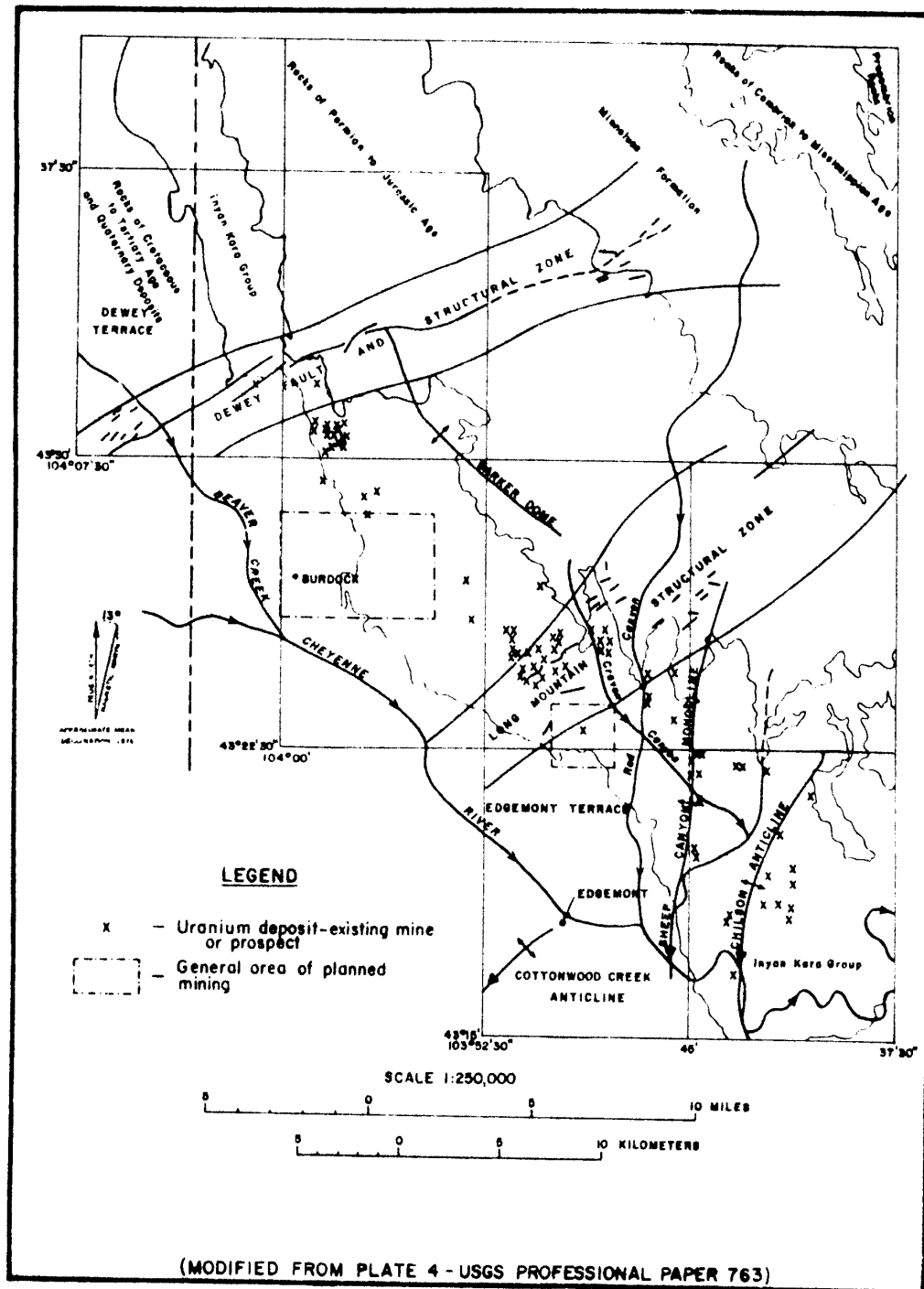


Figure 1 : Generalized Geologic Map of Site Region

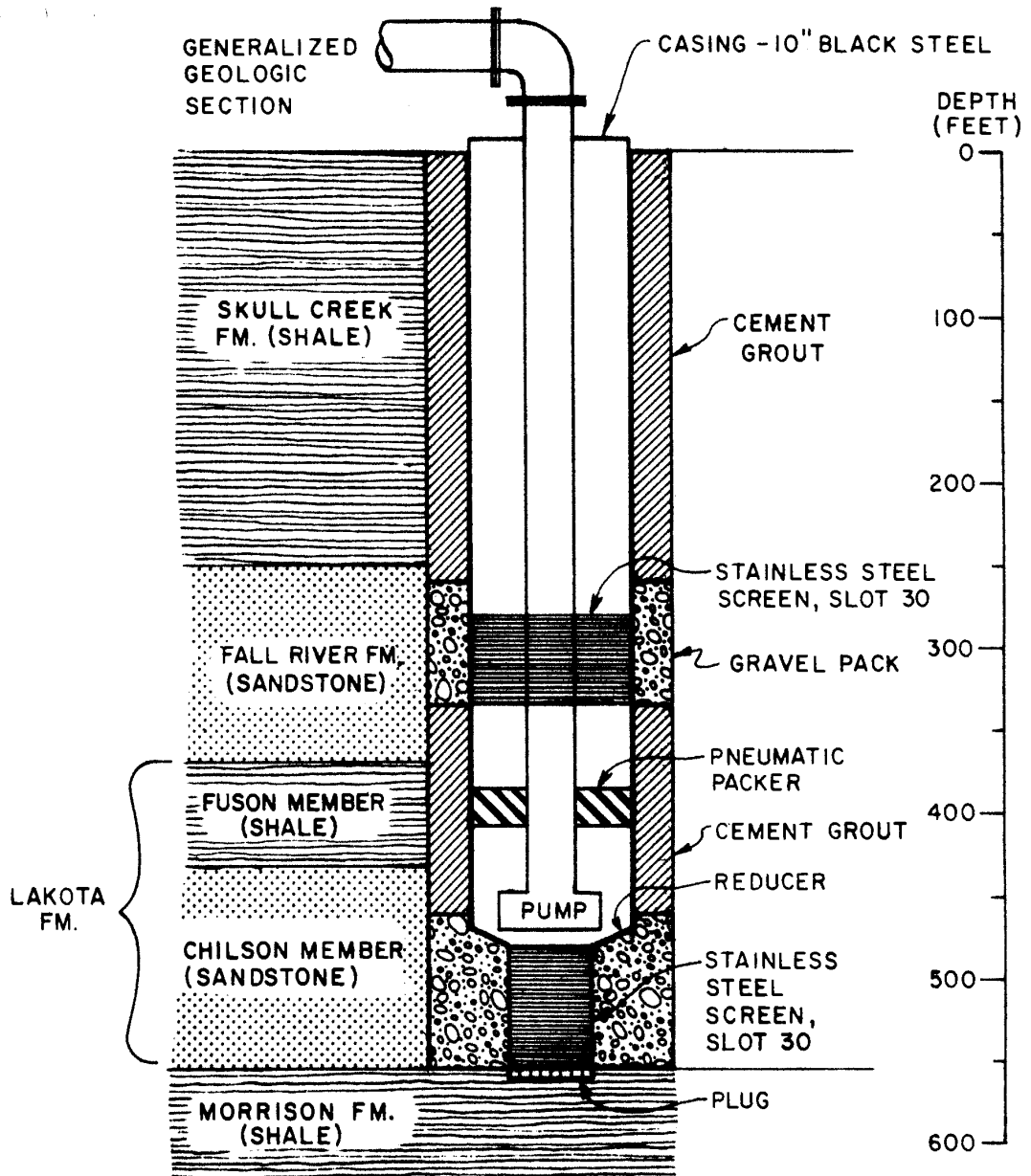


Figure 2 : Burdock Well Profile



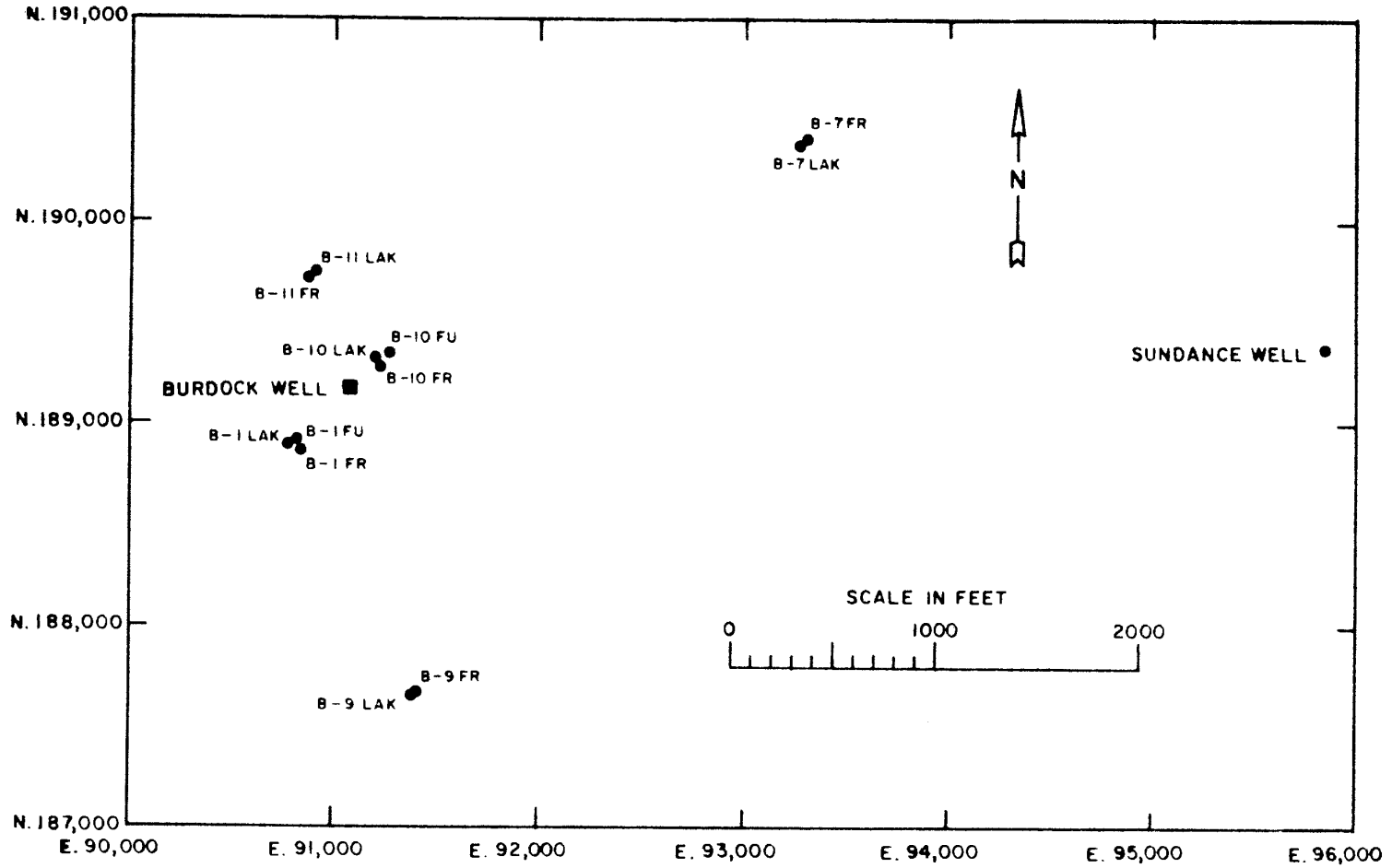


Figure 3: Well Location Map

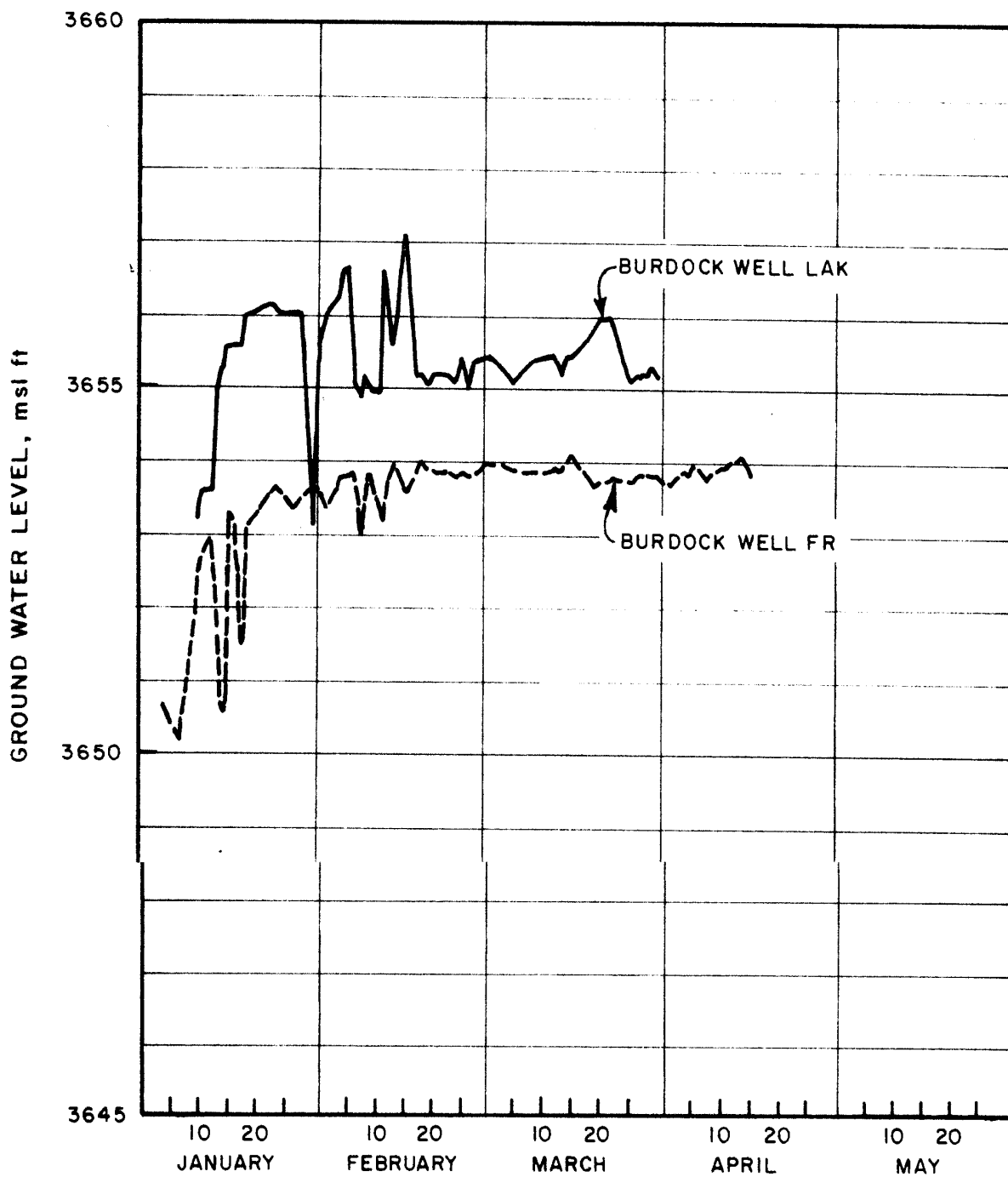


Figure 4 : Hydrographs for Burdock Test Well, January 1 through April 17, 1979

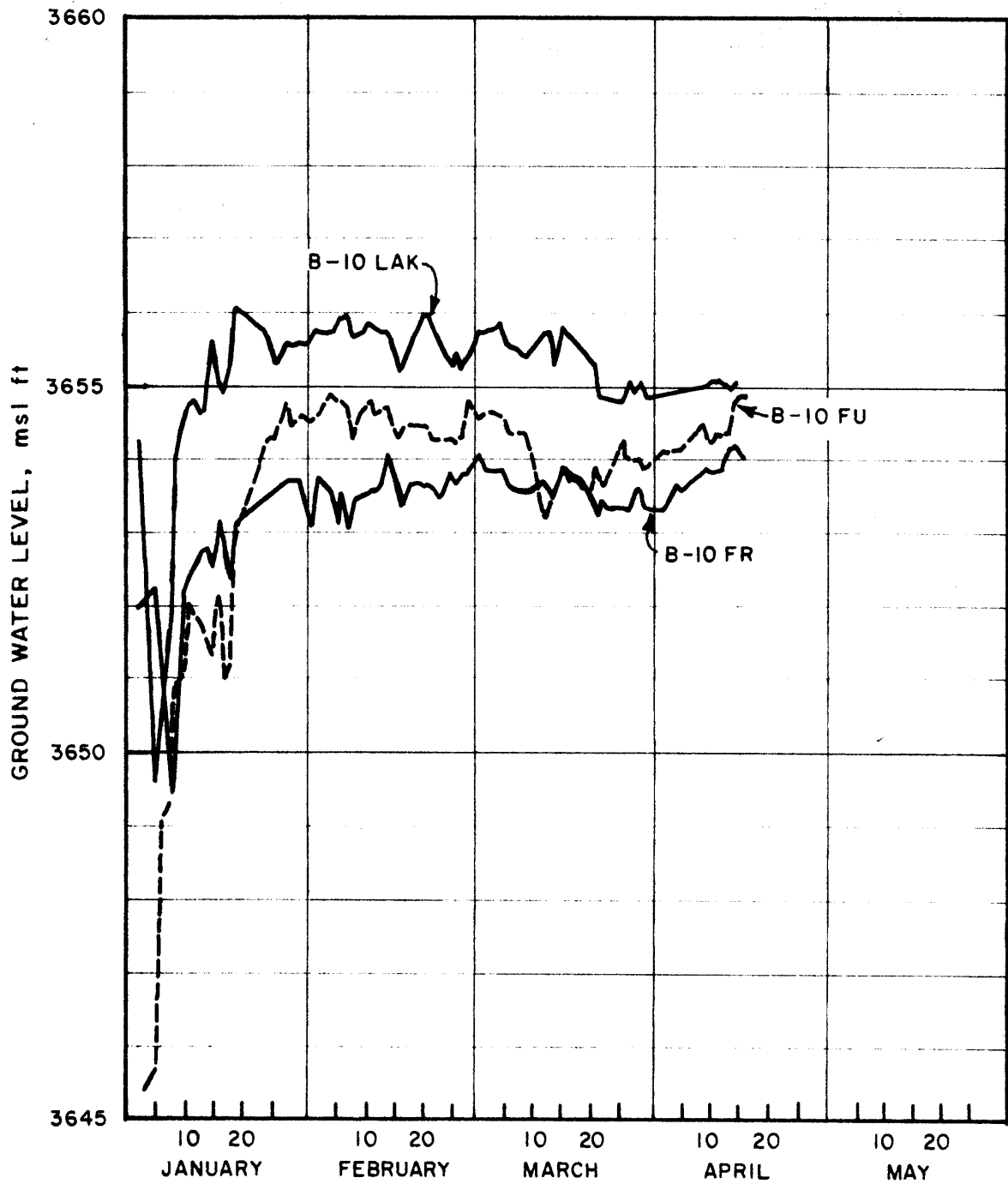


Figure 5 : Hydrographs for B-10 Observation Well Group, January 1 through April 17, 1979

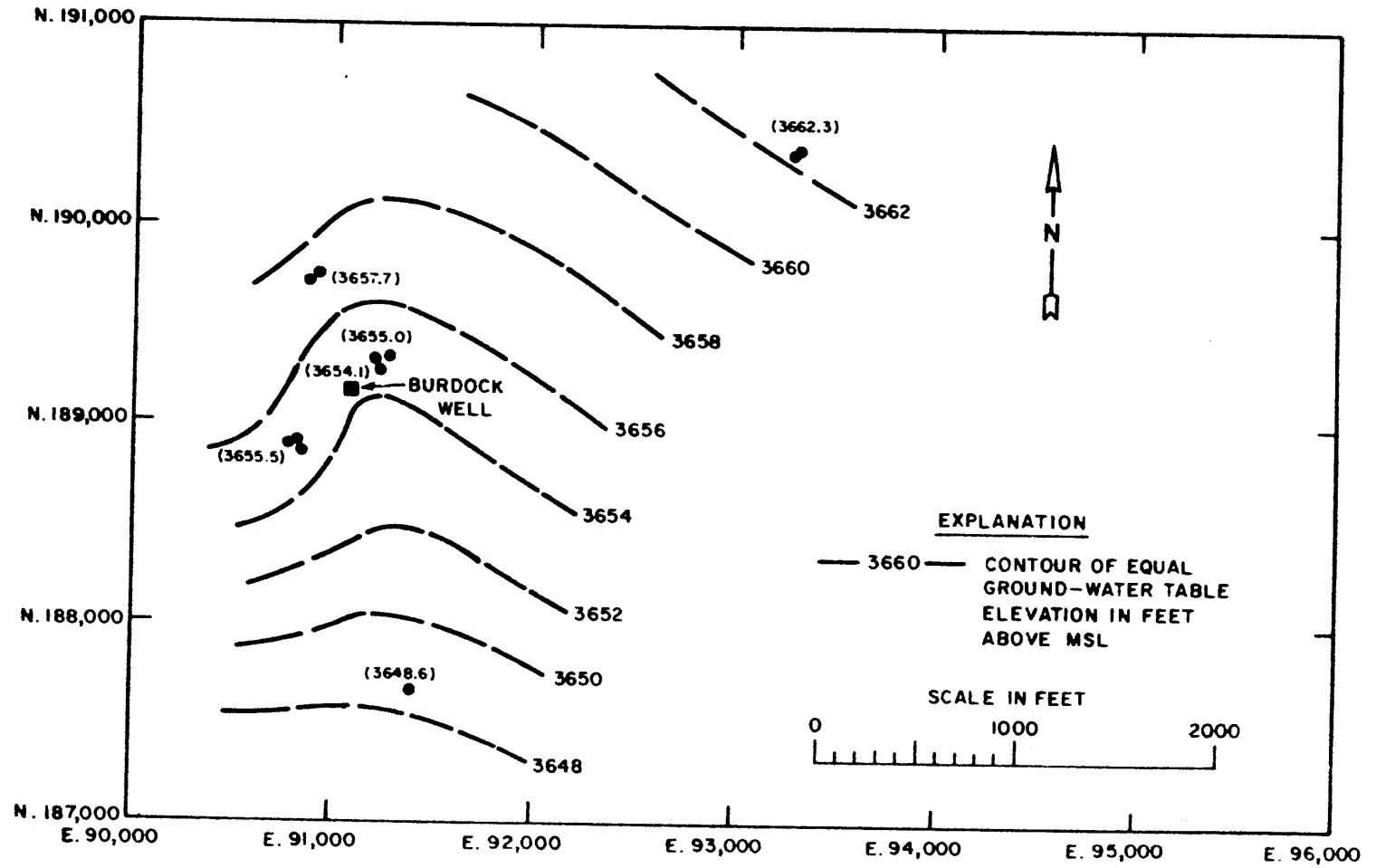


Figure 6 : Pre-Test Ground-Water Level Contour Map for Lakota Aquifer

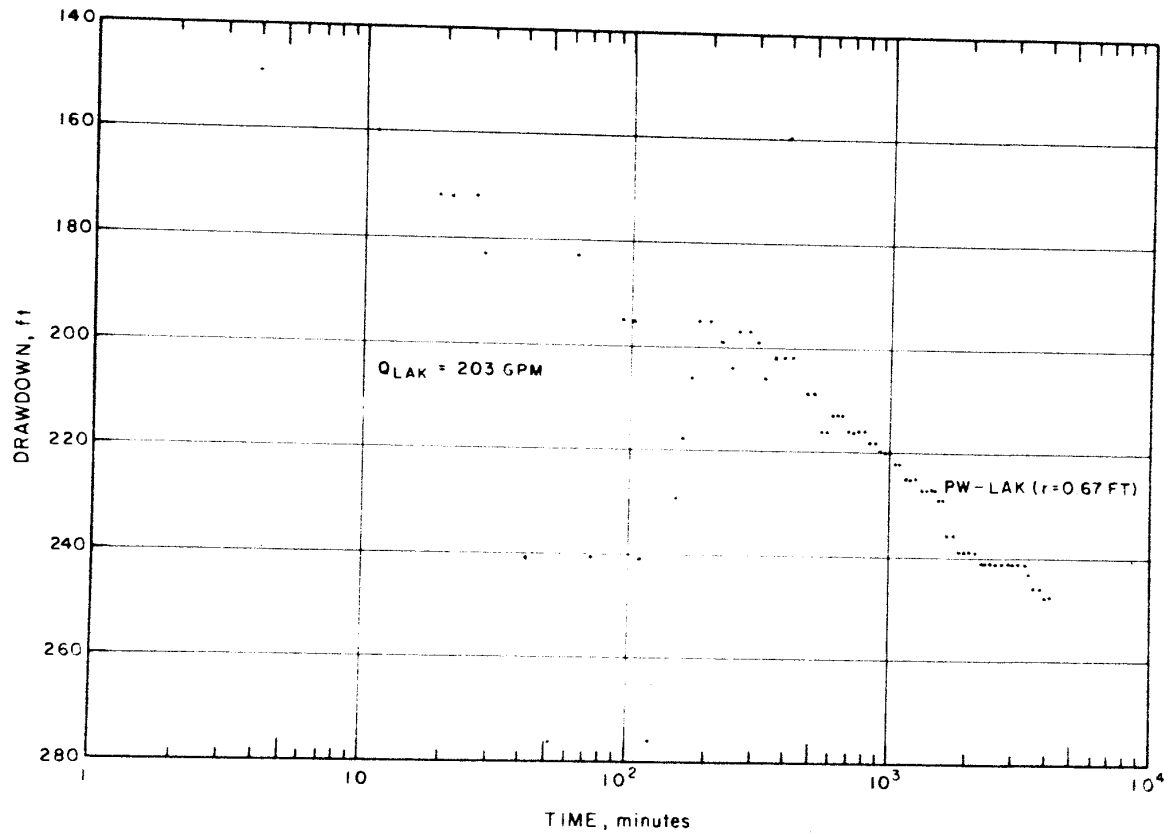


Figure 7: Semilogarithmic Graph of Drawdown for Pumped Well,  
Lakota Aquifer Test

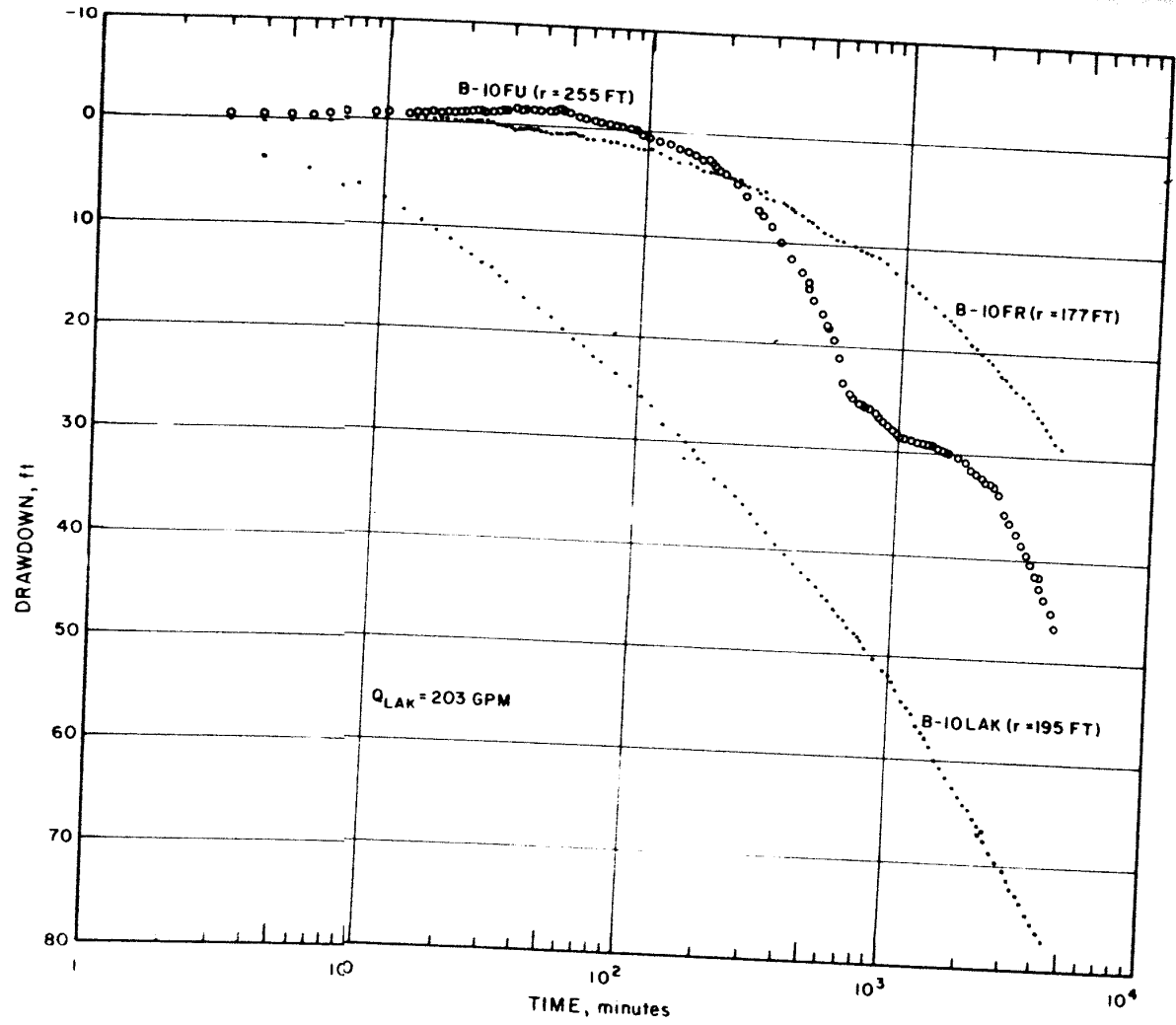


Figure 8 : Semilogarithmic Graphs of Drawdown for B-IO Observation Well Group, Lakota Aquifer Test

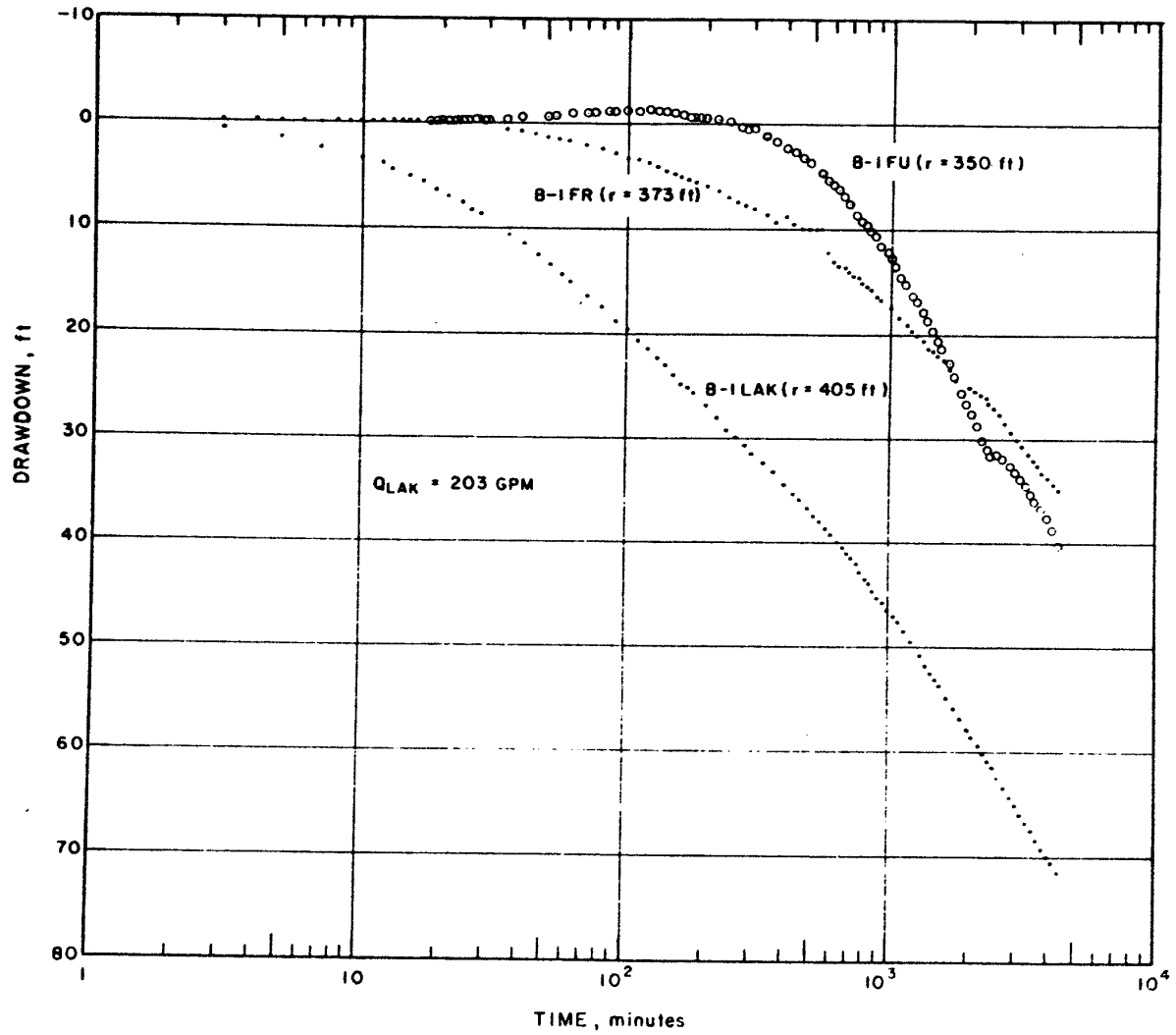


Figure 9: Semilogarithmic Graphs of Drawdown for B-I Observation Well Group, Lakota Aquifer Test

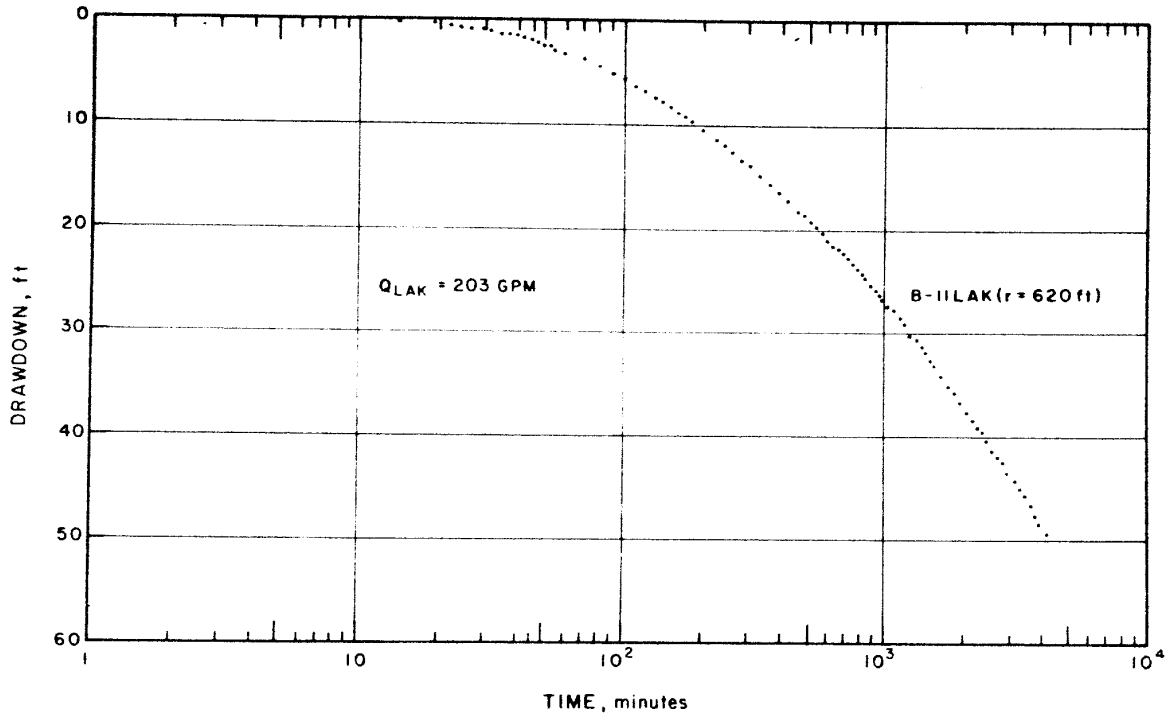


Figure 10: Semilogarithmic Graph of Drawdown for B-II Observation Well Group,  
Lakota Aquifer Test



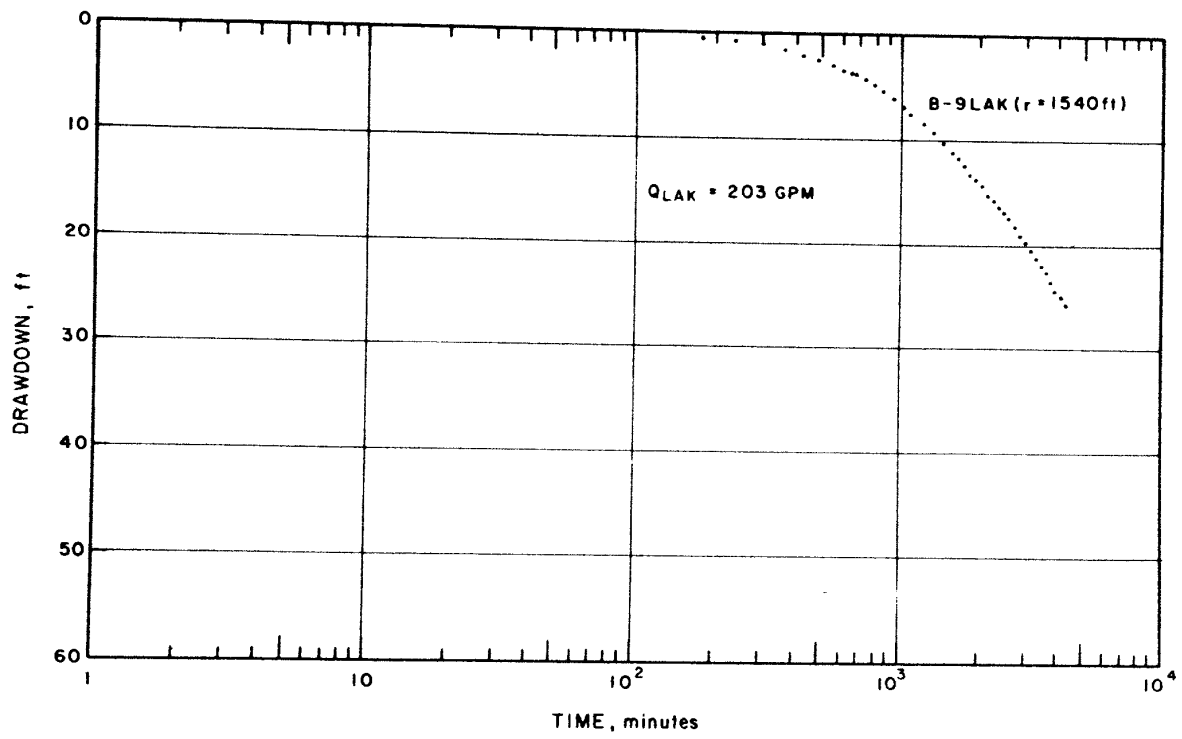


Figure II: Semilogarithmic Graph of Drawdown for B-9 Observation Well Group, Lakota Aquifer Test

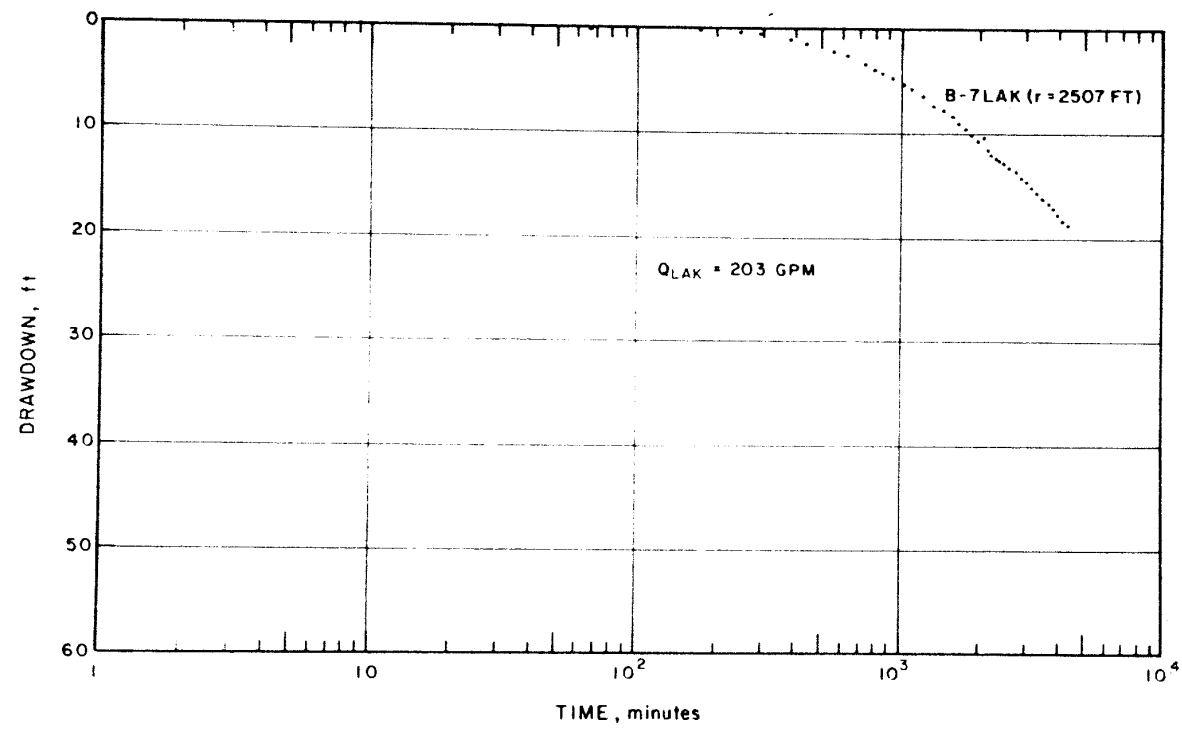


Figure 12: Semilogarithmic Graph of Drawdown for B-7 Observation Well Group, Lakota Aquifer Test

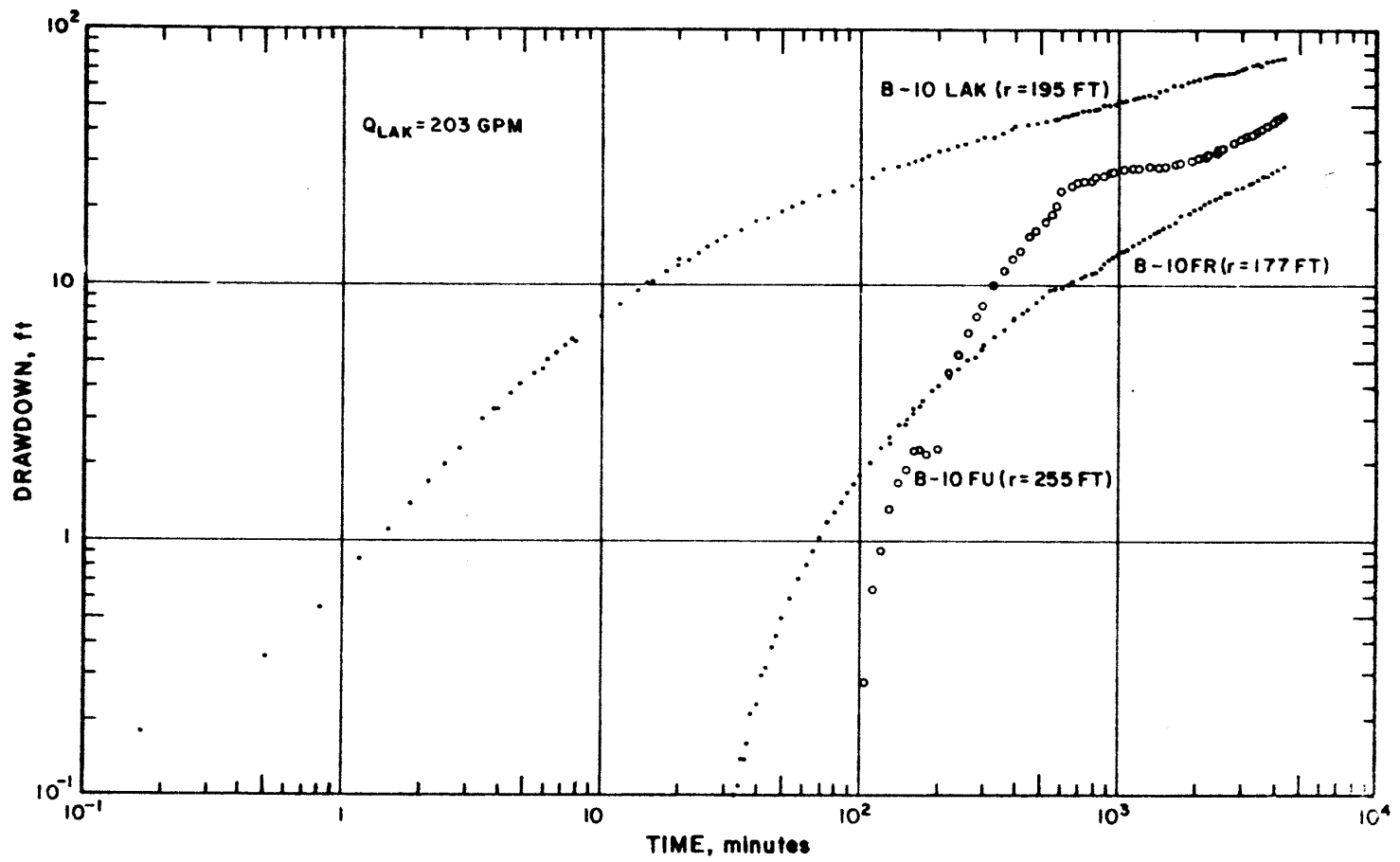


Figure 13 : Logarithmic Graphs of Drawdown for B-10 Observation Well Group, Lakota Aquifer Test

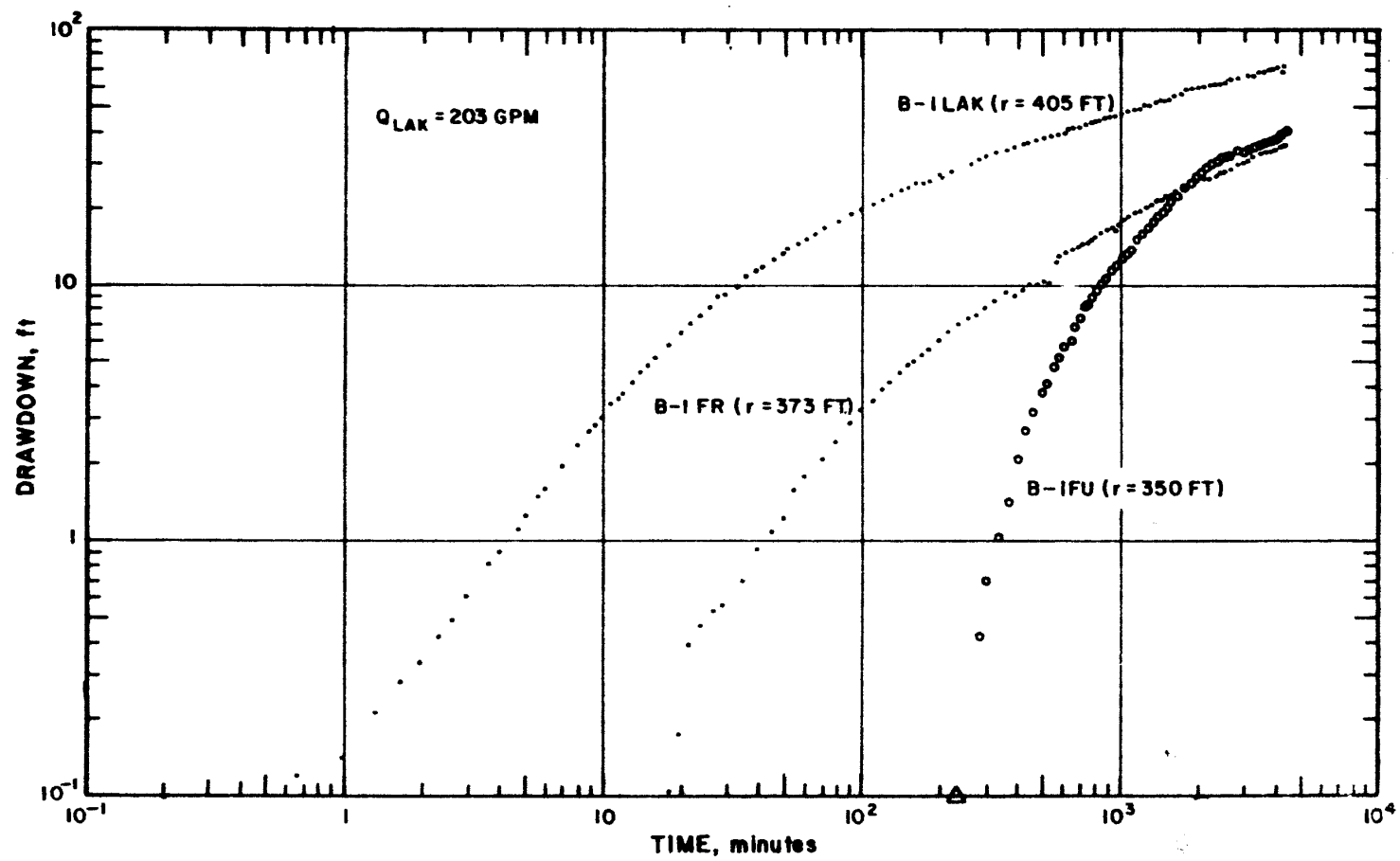


Figure 14 : Logarithmic Graphs of Drawdown for B-1 Observation Well Group, Lakota Aquifer Test

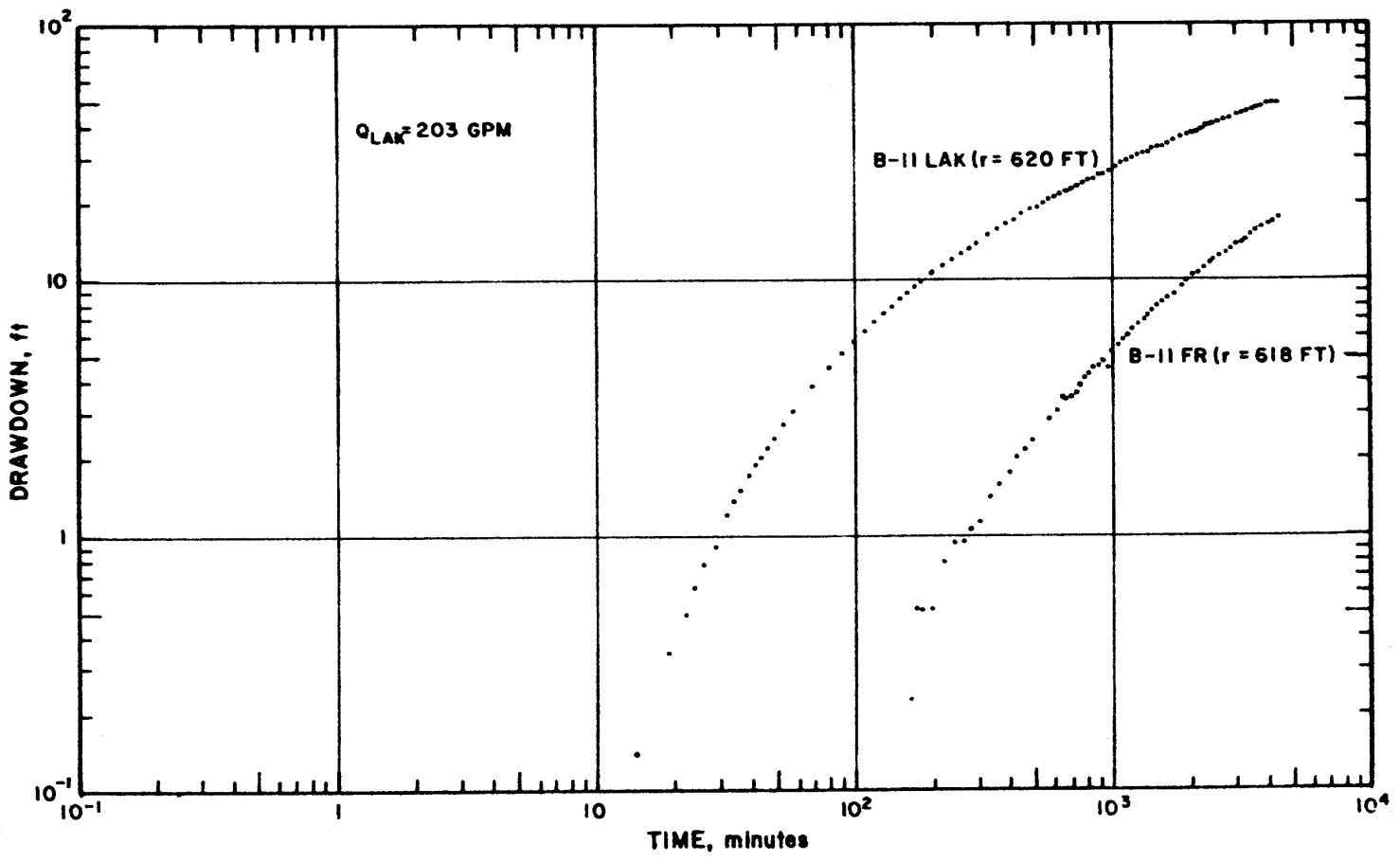


Figure 15: Logarithmic Graphs of Drawdown for B-II Observation Well Group, Lakota Aquifer Test

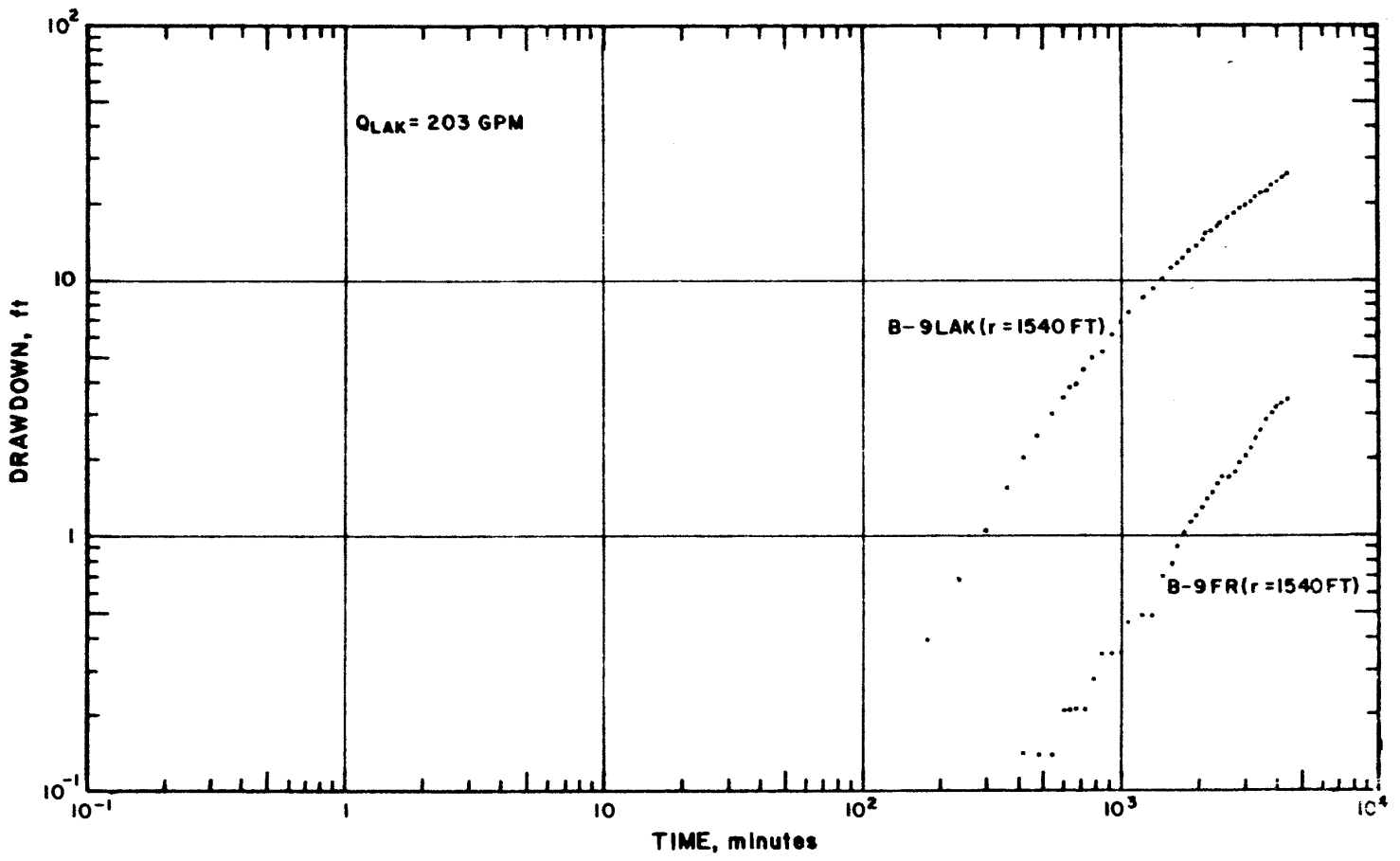


Figure 16 : Logarithmic Graphs of Drawdown for B-9 Observation Well Group, Lakota Aquifer Test

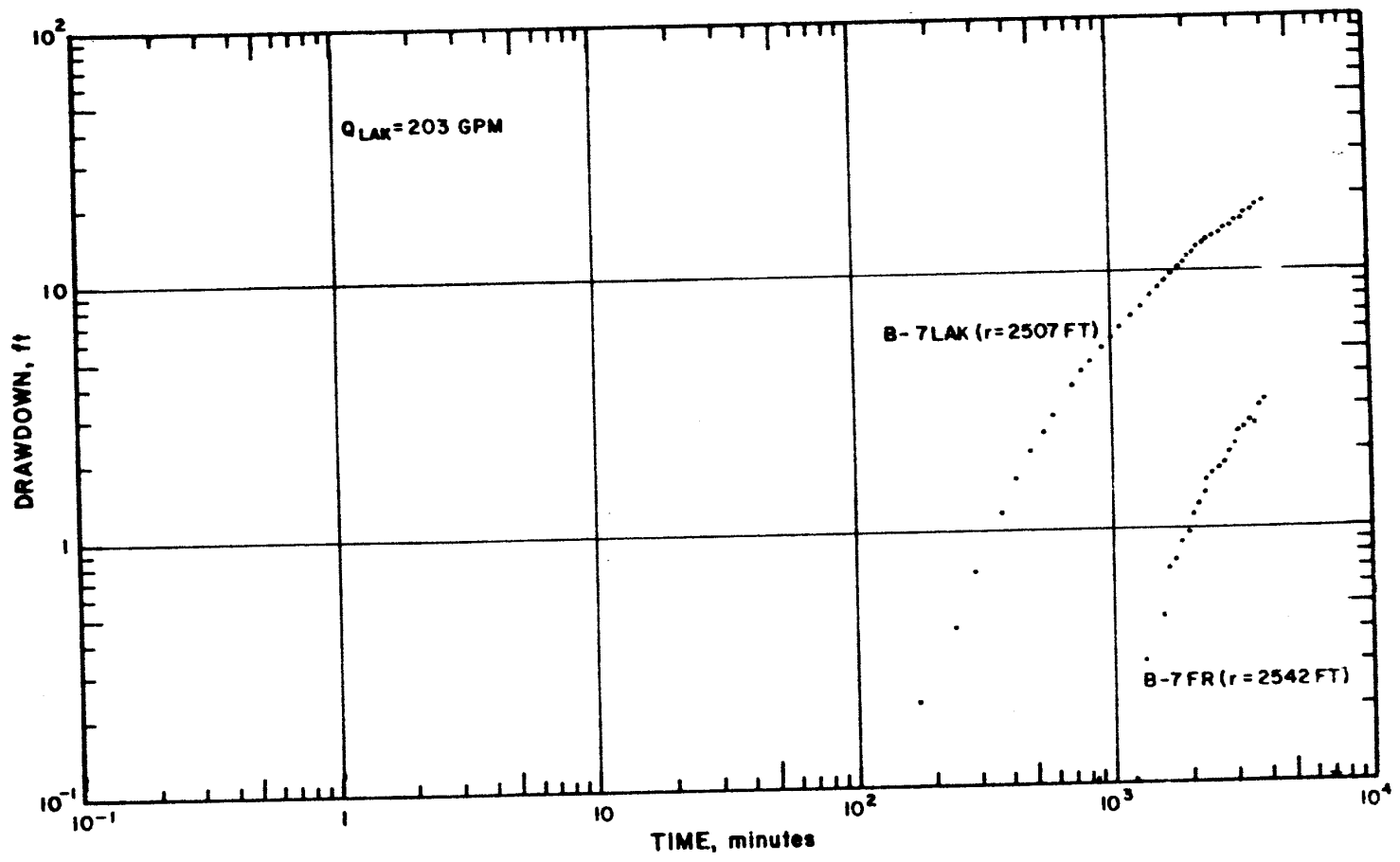


Figure 17 : Logarithmic Graphs of Drawdown for B-7 Observation Well Group, Lakota Aquifer Test

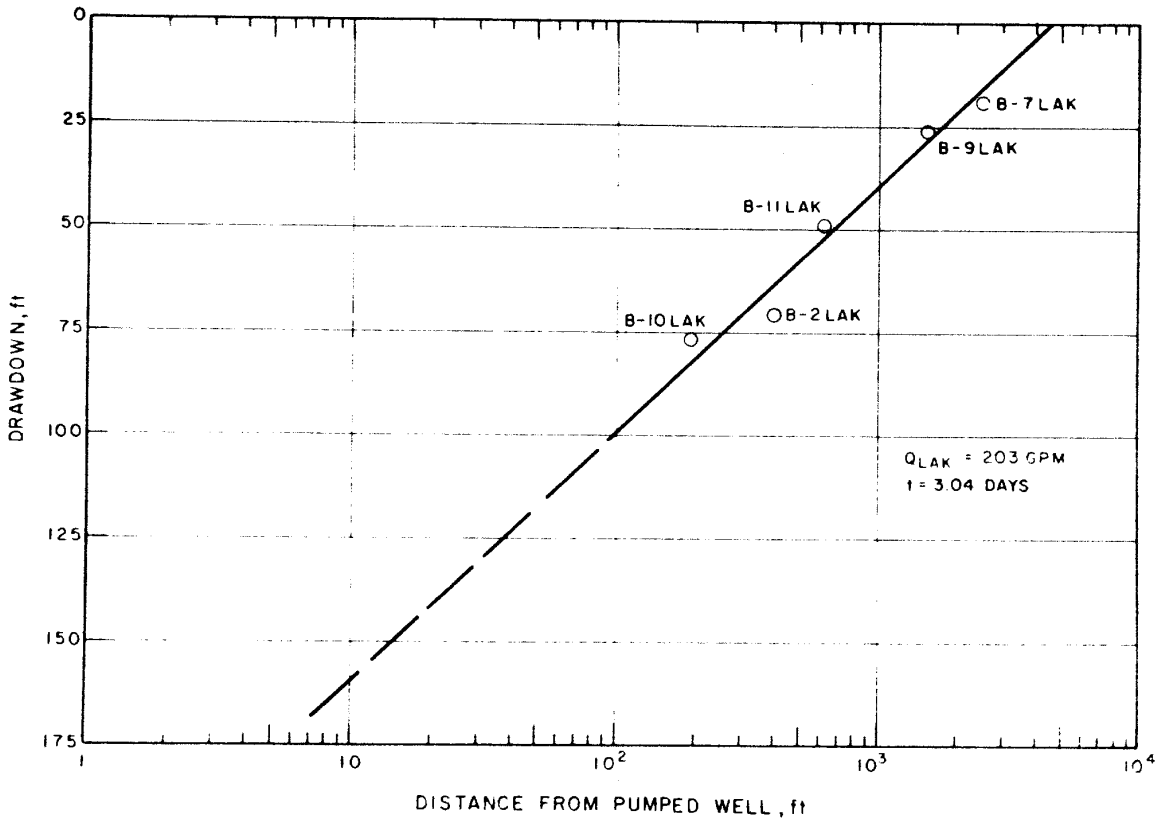


Figure 18 : Semilogarithmic Graph of Distance vs. Drawdown at End of Pumping Test, Lakota Aquifer Test



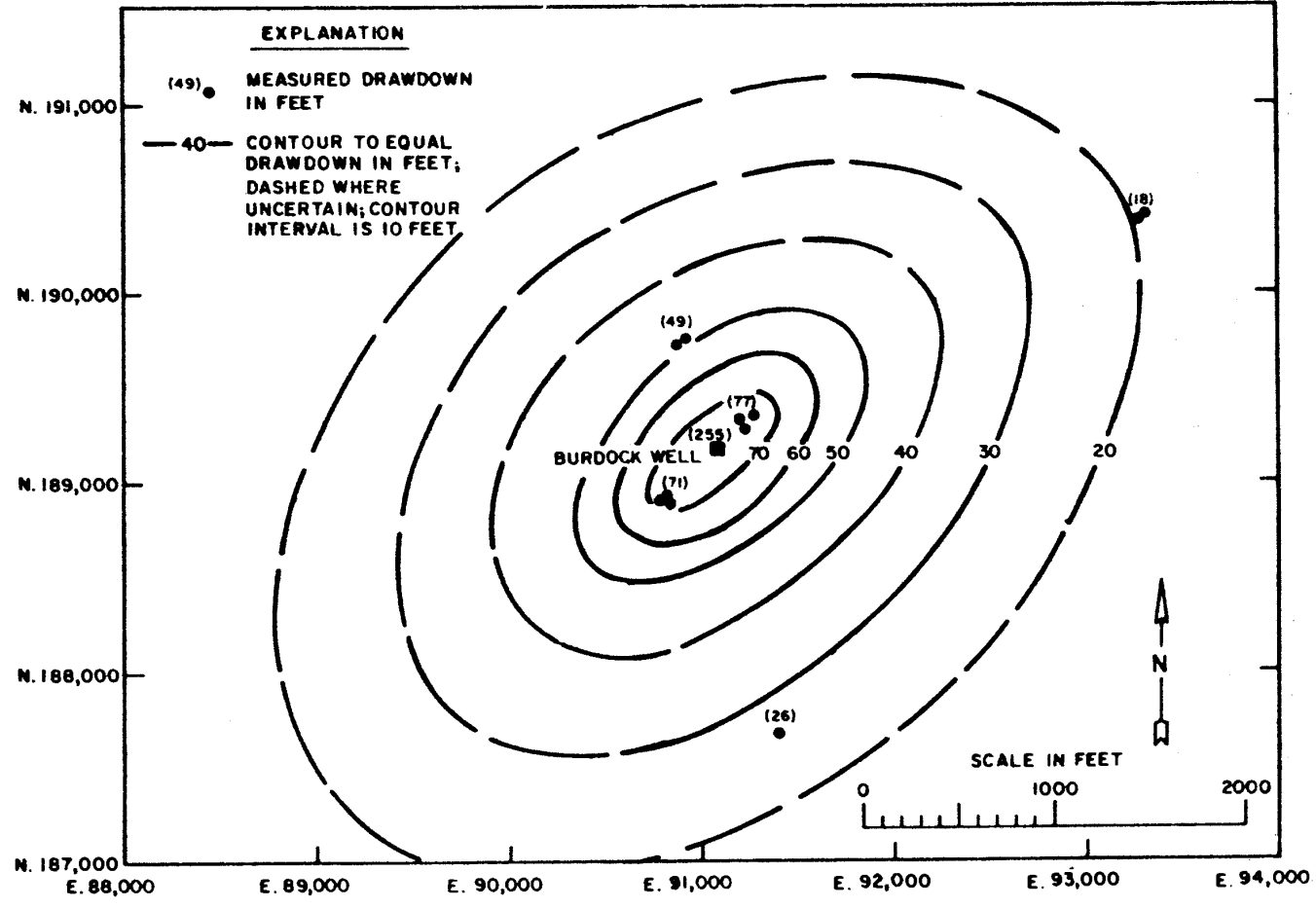


Figure 19 : Drawdown in Lakota Aquifer at End of Lakota Test

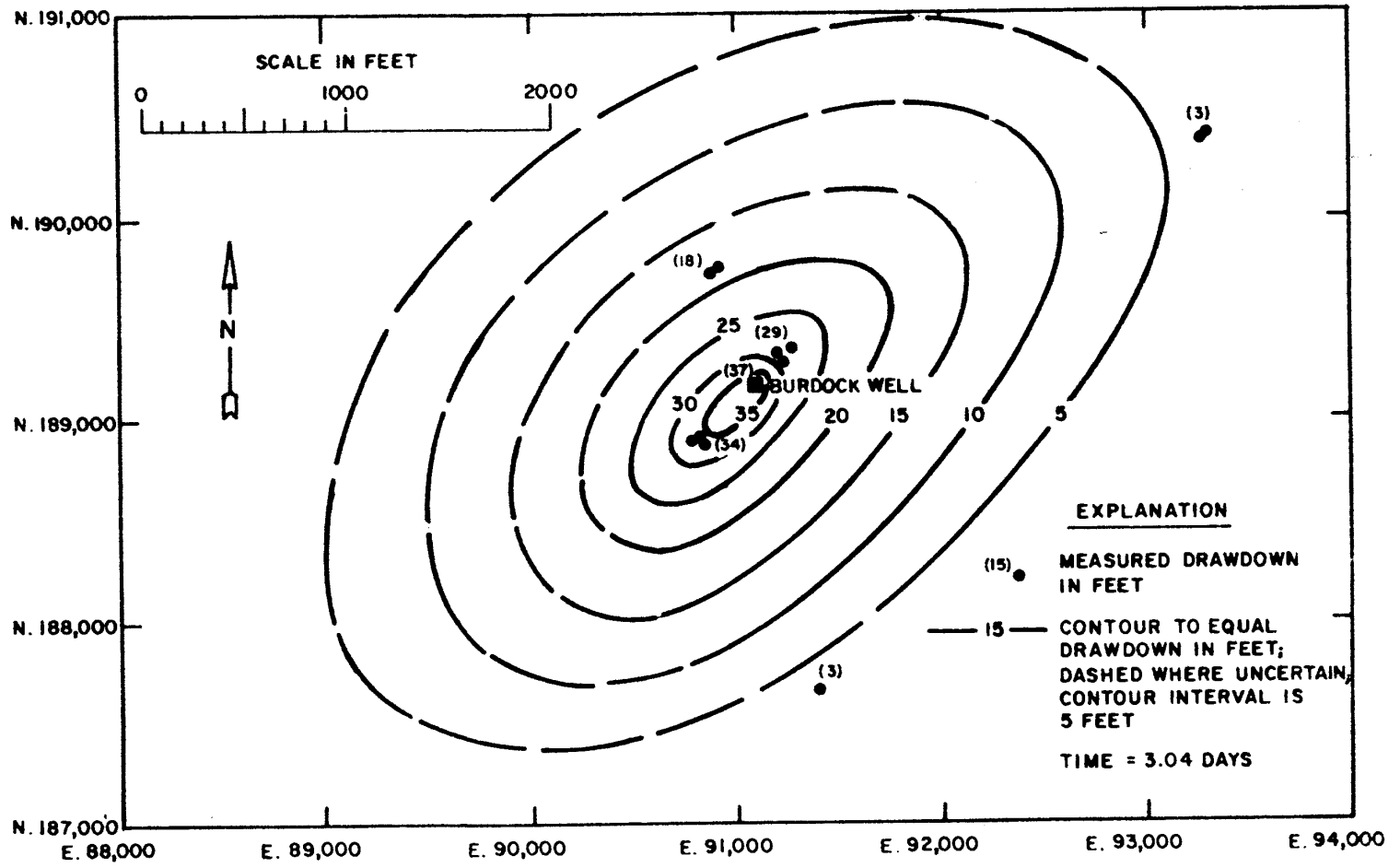


Figure 20 : Drawdown in Fall River Aquifer at End of Lakota Test

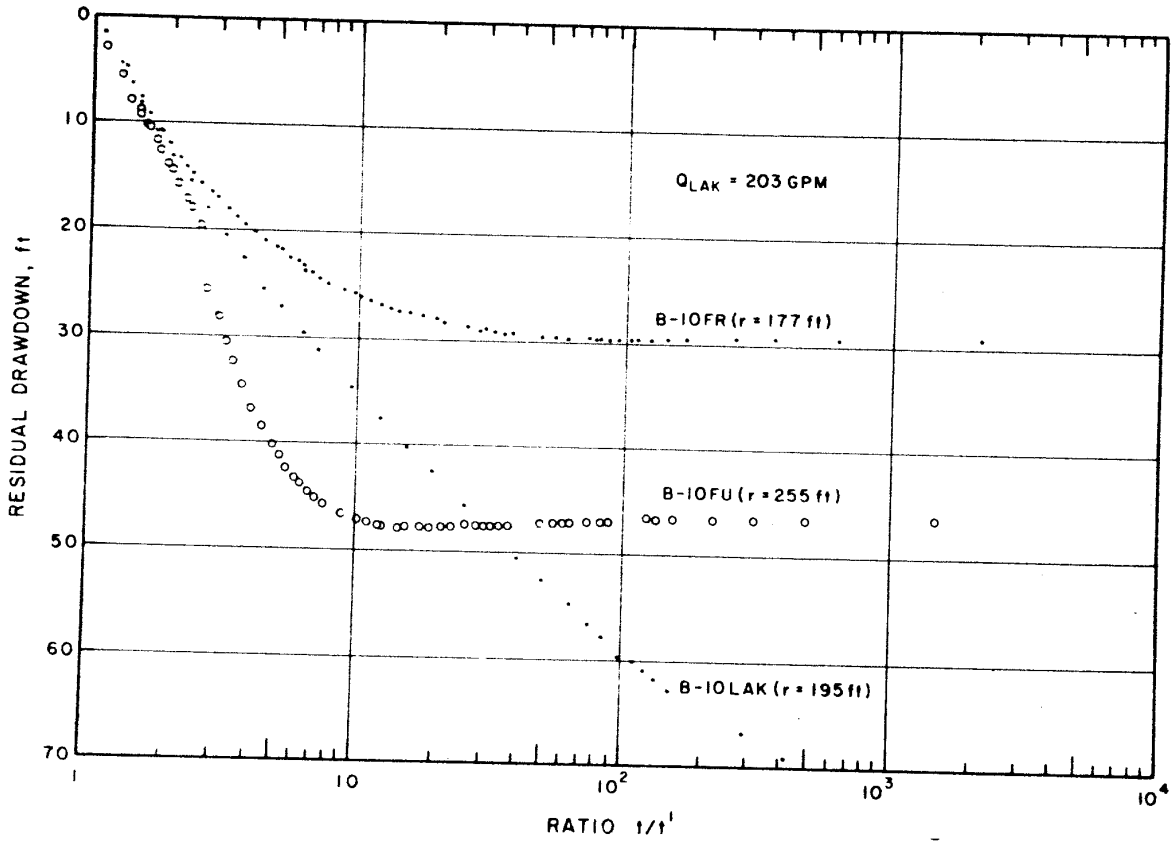


Figure 21: Recovery Graphs for B-IO Observation Well Group, Lakota Aquifer Test

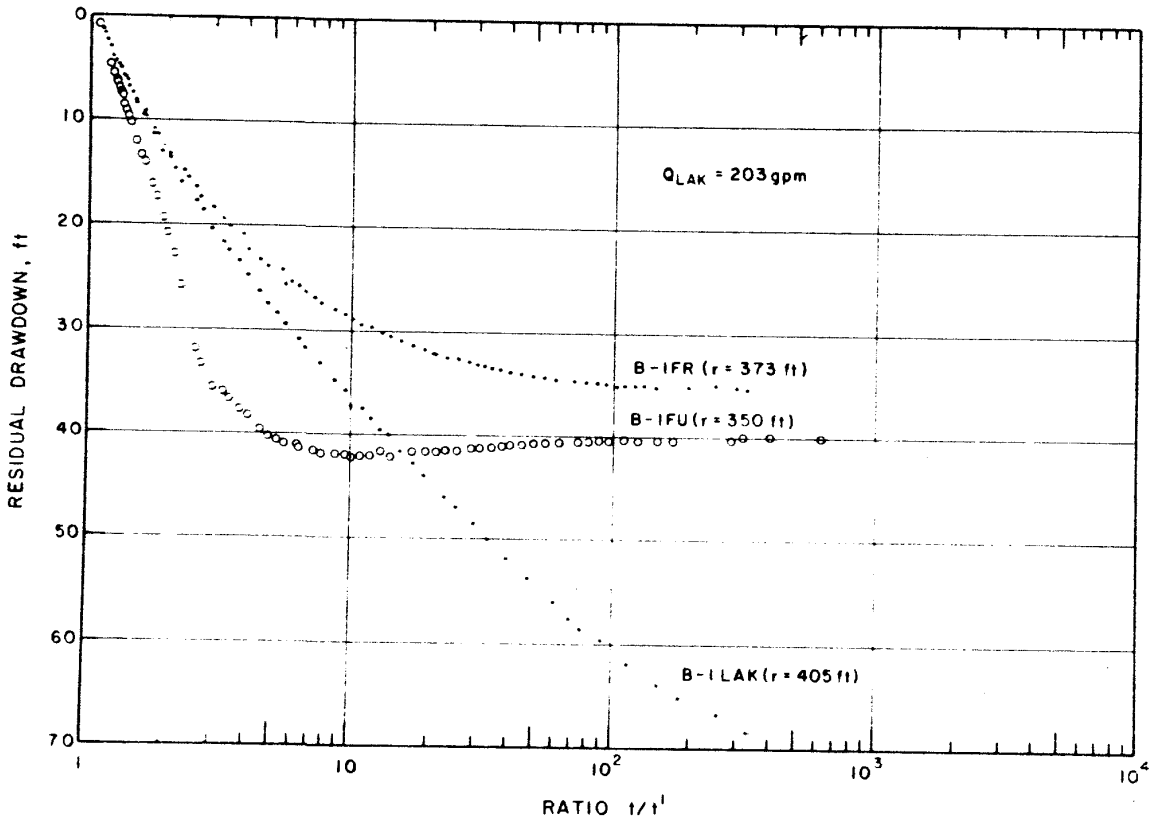


Figure 22: Recovery Graphs for B-1 Observation Well Group, Lakota Aquifer Test

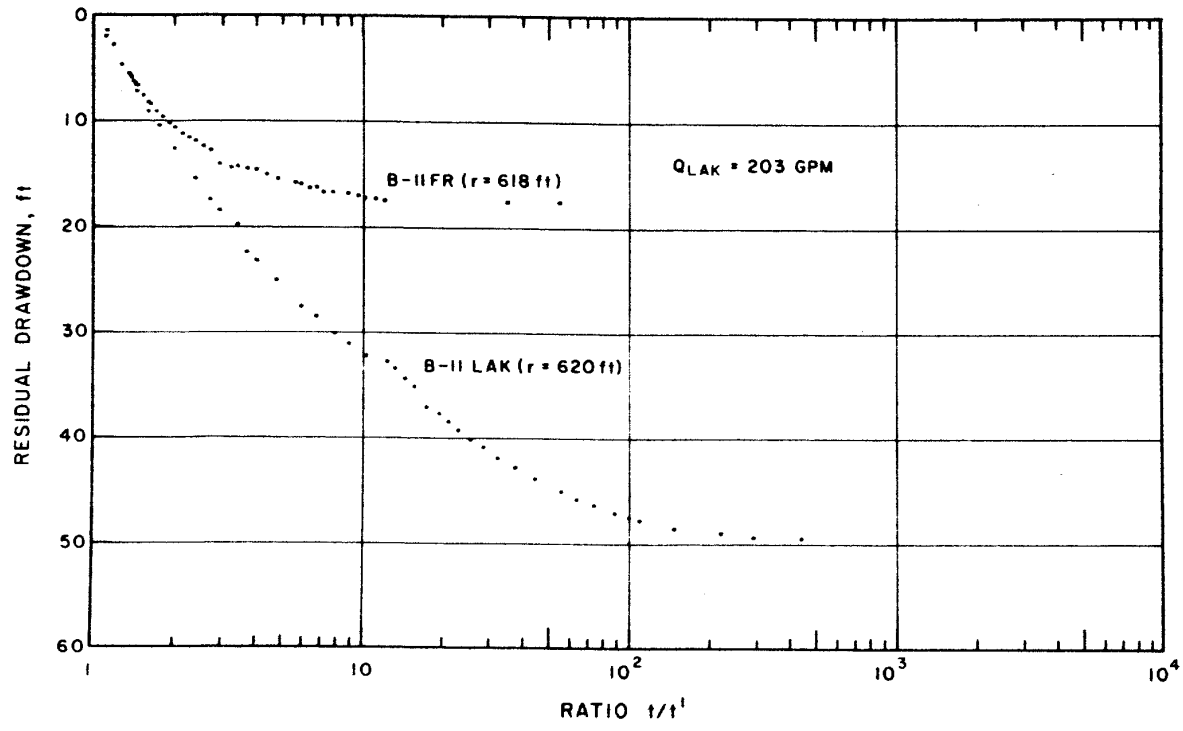


Figure 23: Recovery Graphs for B-II Observation Well Group, Lakota Aquifer Test

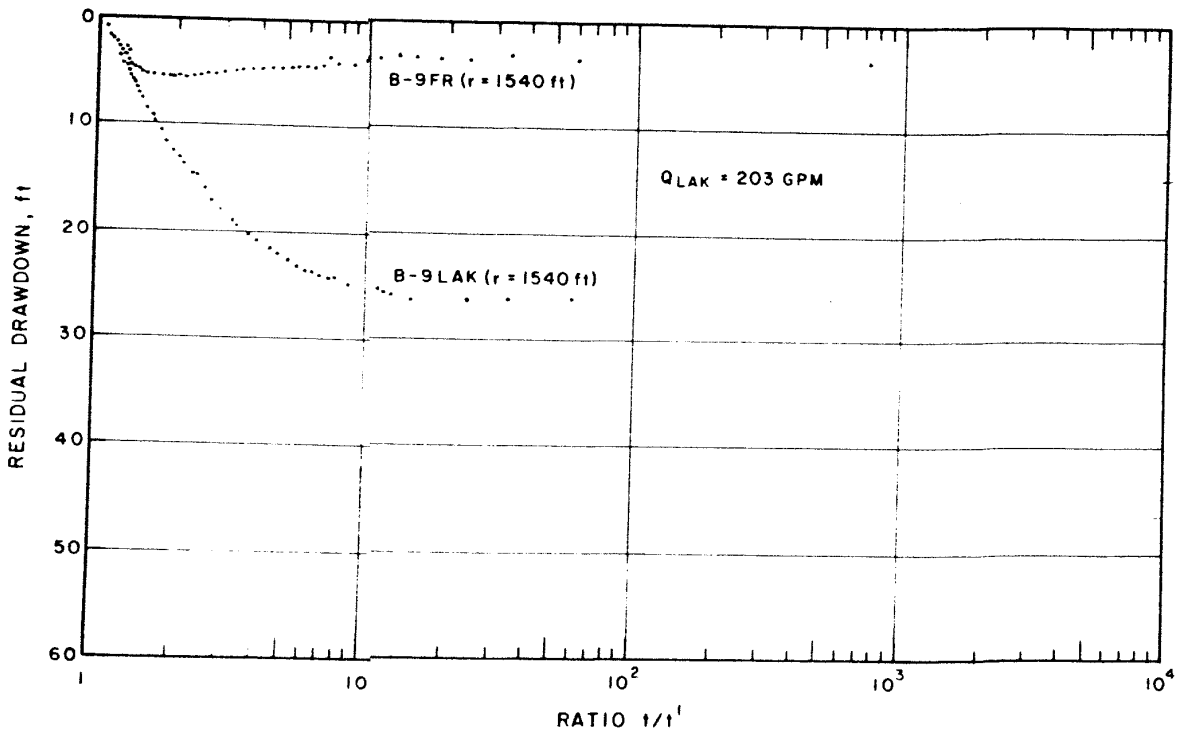


Figure 24 Recovery Graphs for B-9 Observation Well Group, Lakota Aquifer Test

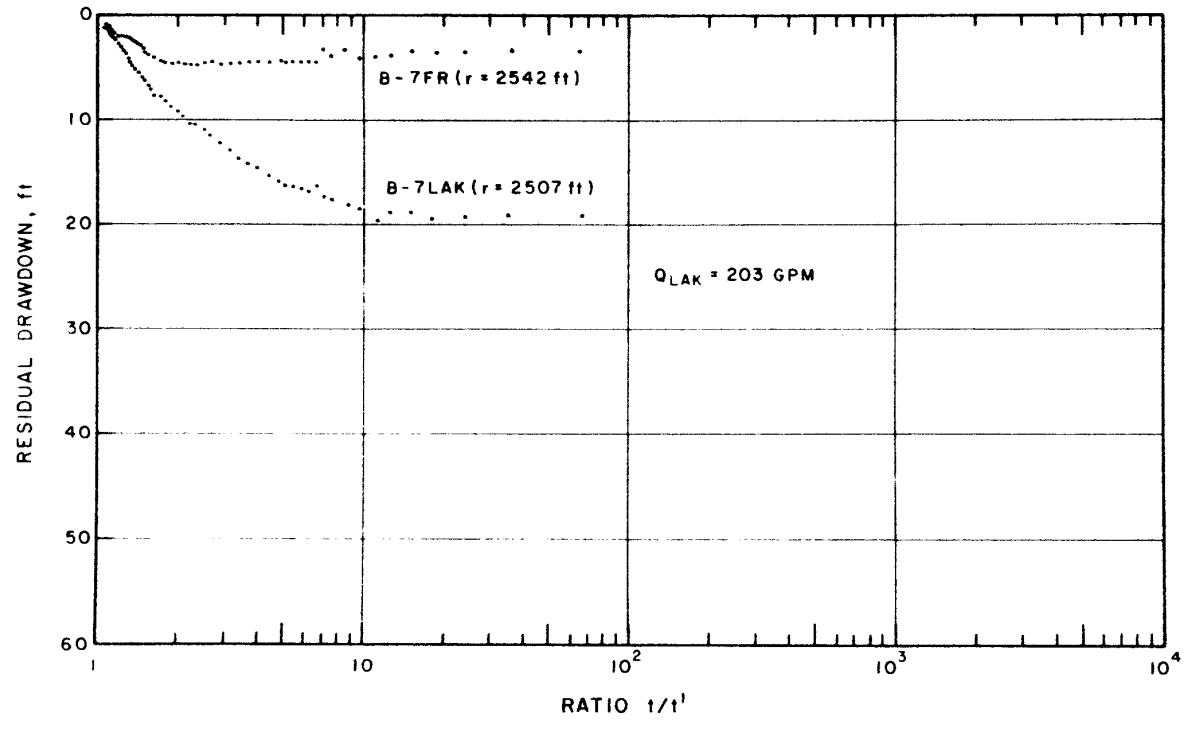


Figure 25: Recovery Graphs for B-7 Observation Well Group, Lakota Aquifer Test

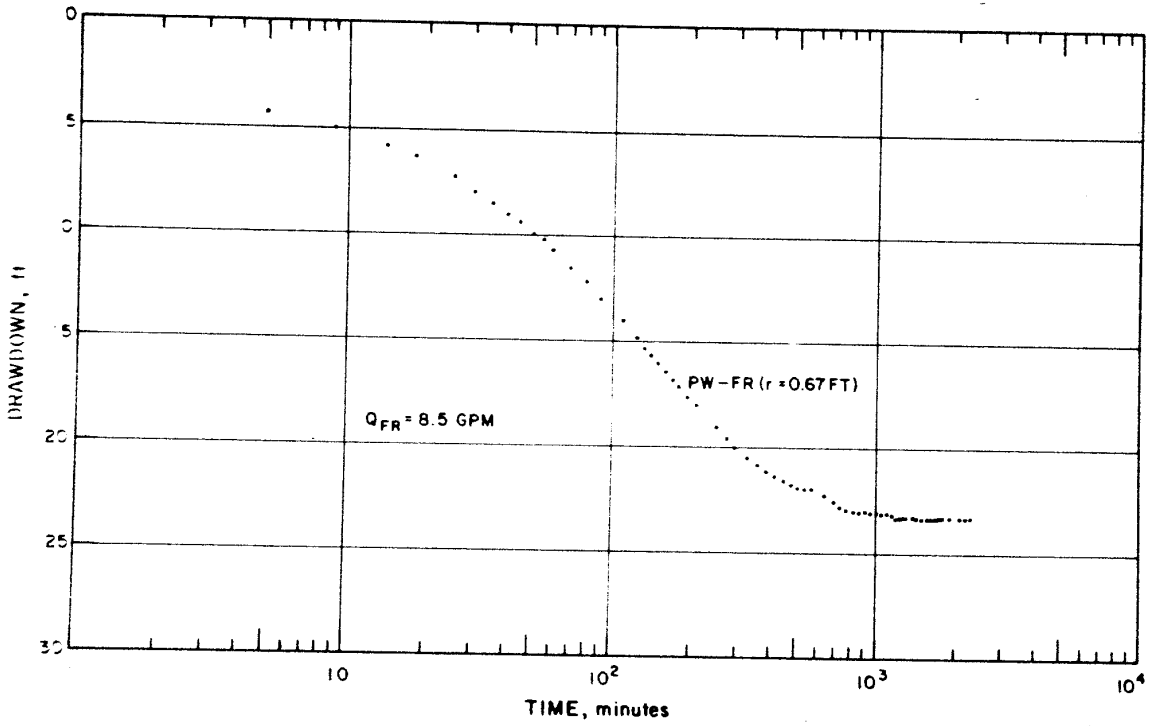


Figure 26: Semilogarithmic Graph of Drawdown for the Pumped Well, Fall River Aquifer Test



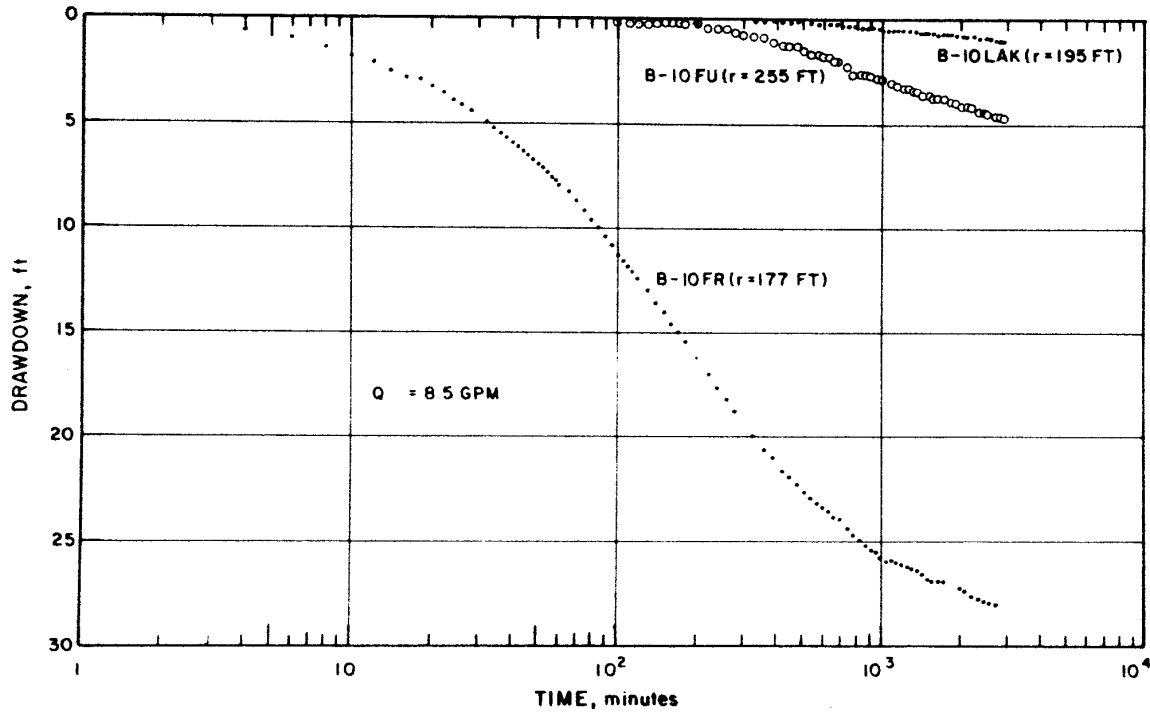


Figure 27: Semilogarithmic Graphs of Drawdown for B-10 Observation Well Group, Fall River Aquifer Test

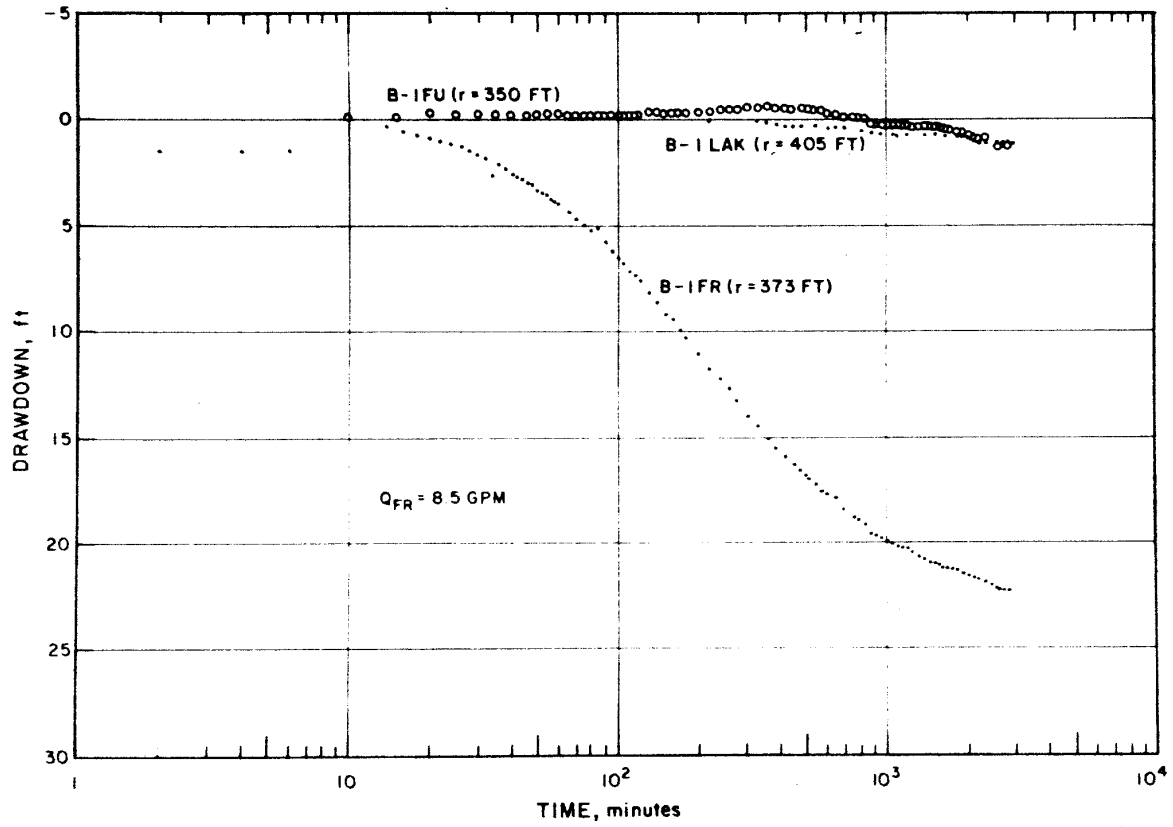


Figure 28 : Semilogarithmic Graphs of Drawdown for B-I Observation Well Group, Fall River Aquifer Test

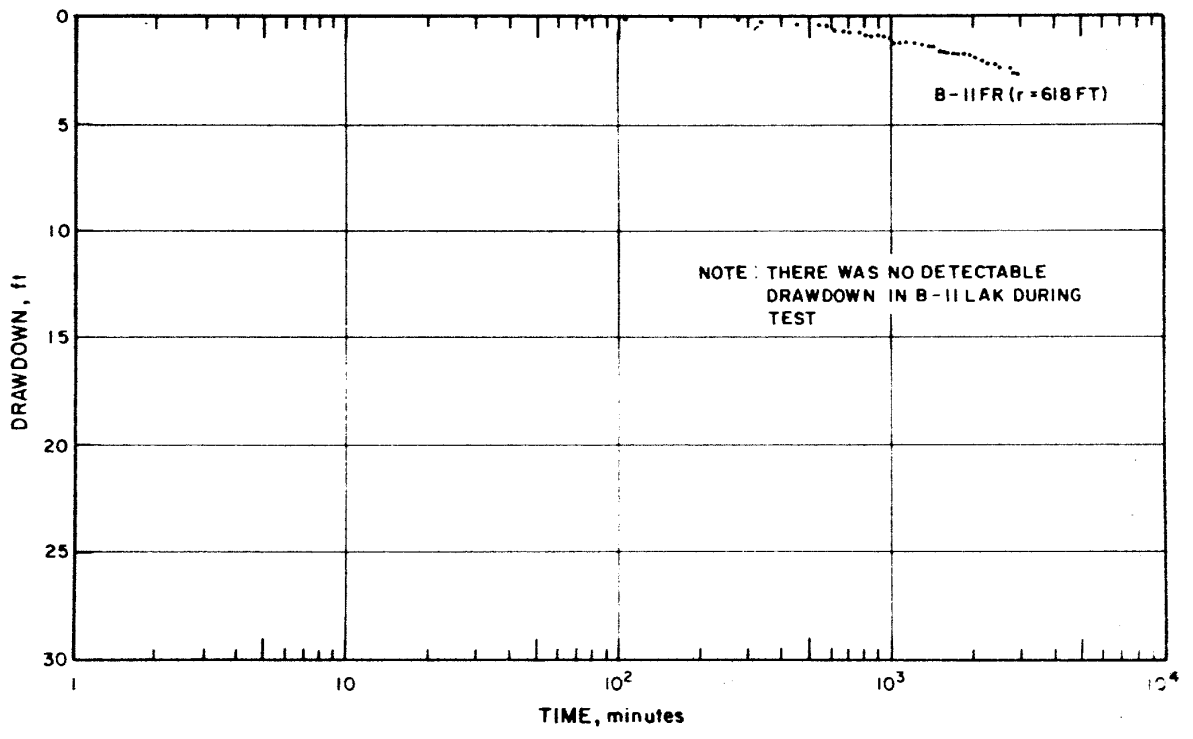


Figure 29: Semilogarithmic Graph of Drawdown for B-II Observation Well Group, Fall River Aquifer Test

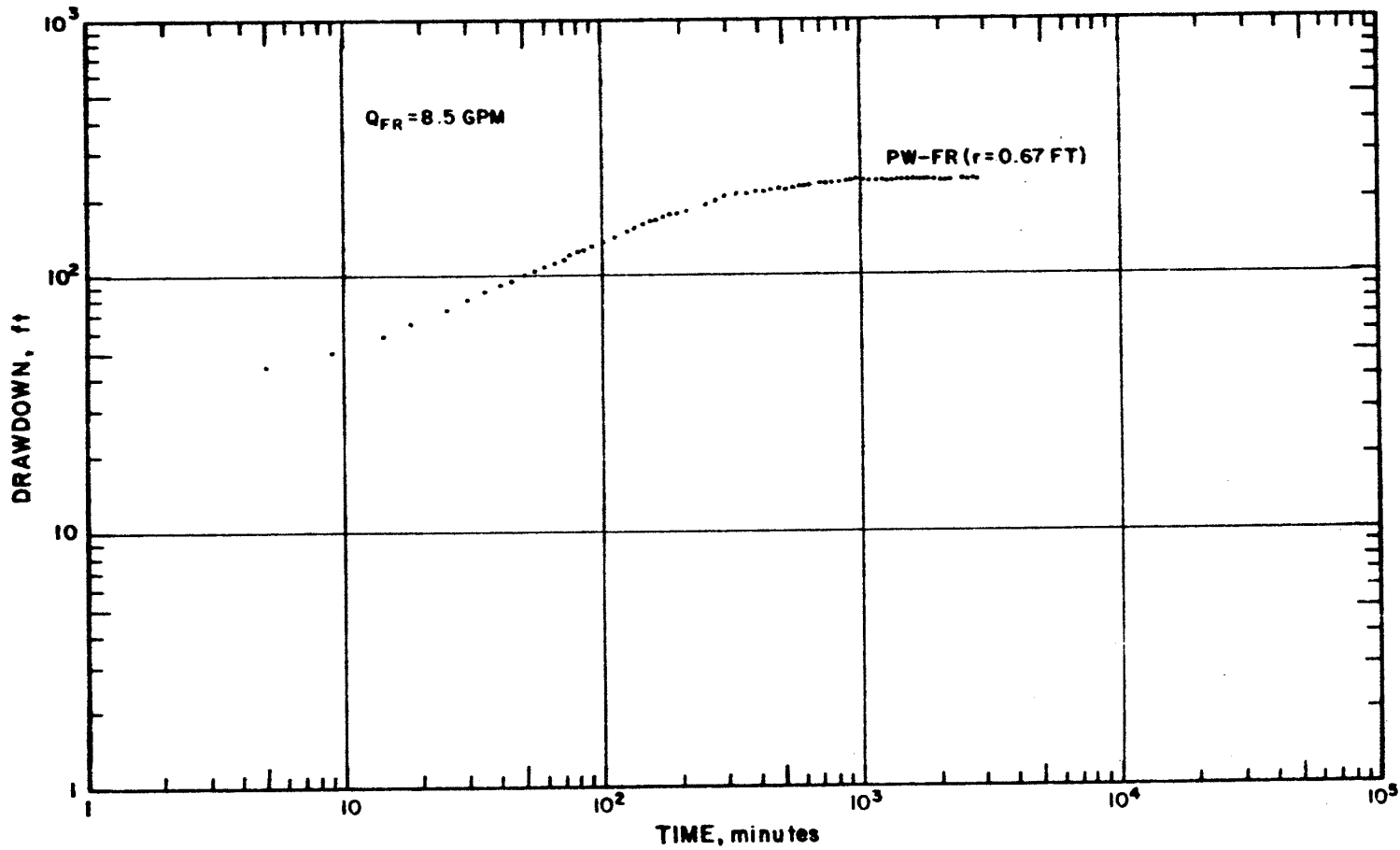


Figure 30: Logarithmic Graph of Drawdown for Pumped Well, Fall River Aquifer Test

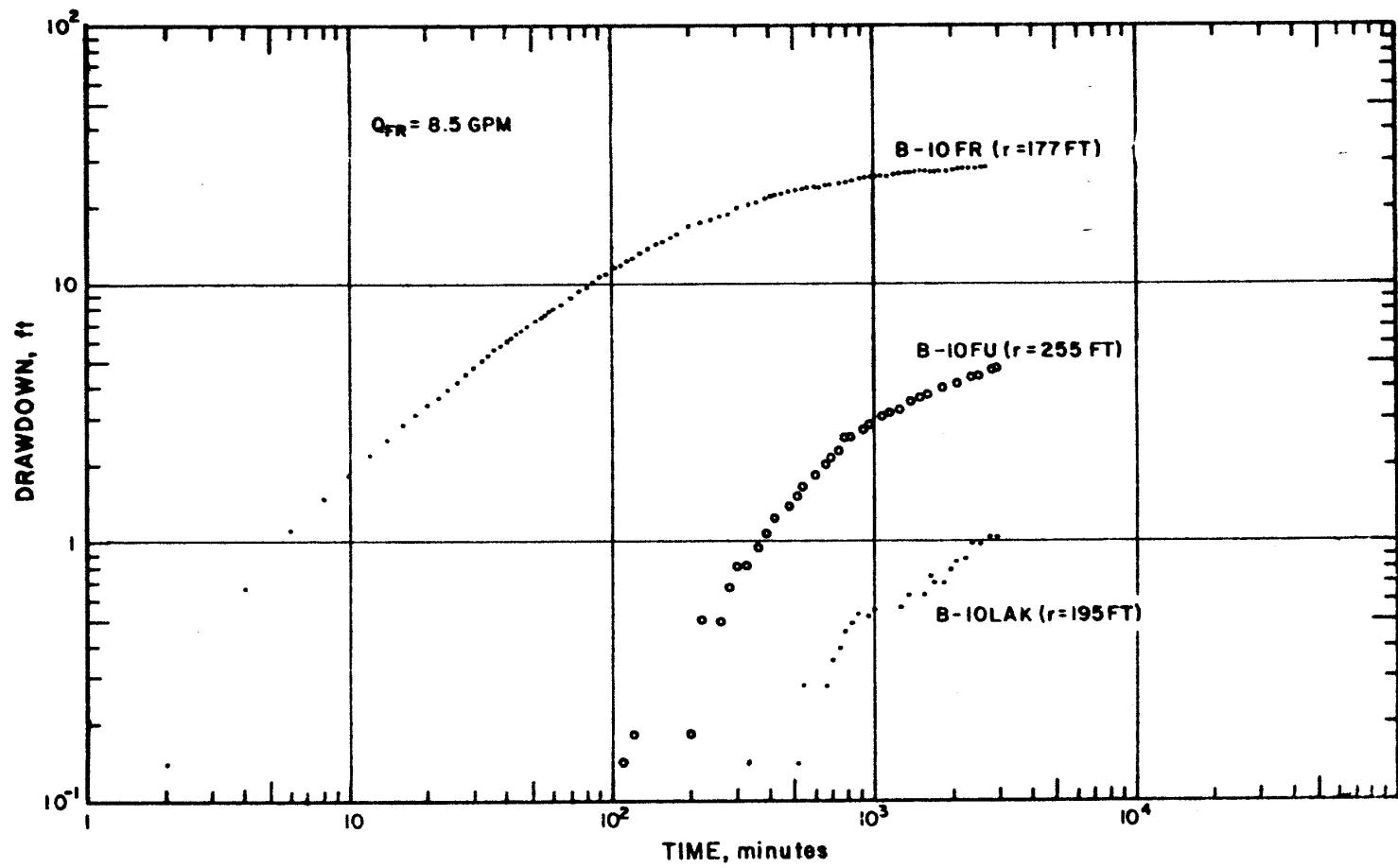


Figure 31: Logarithmic Graphs of Drawdown for B-10 Observation Well Group, Fall River Aquifer Test

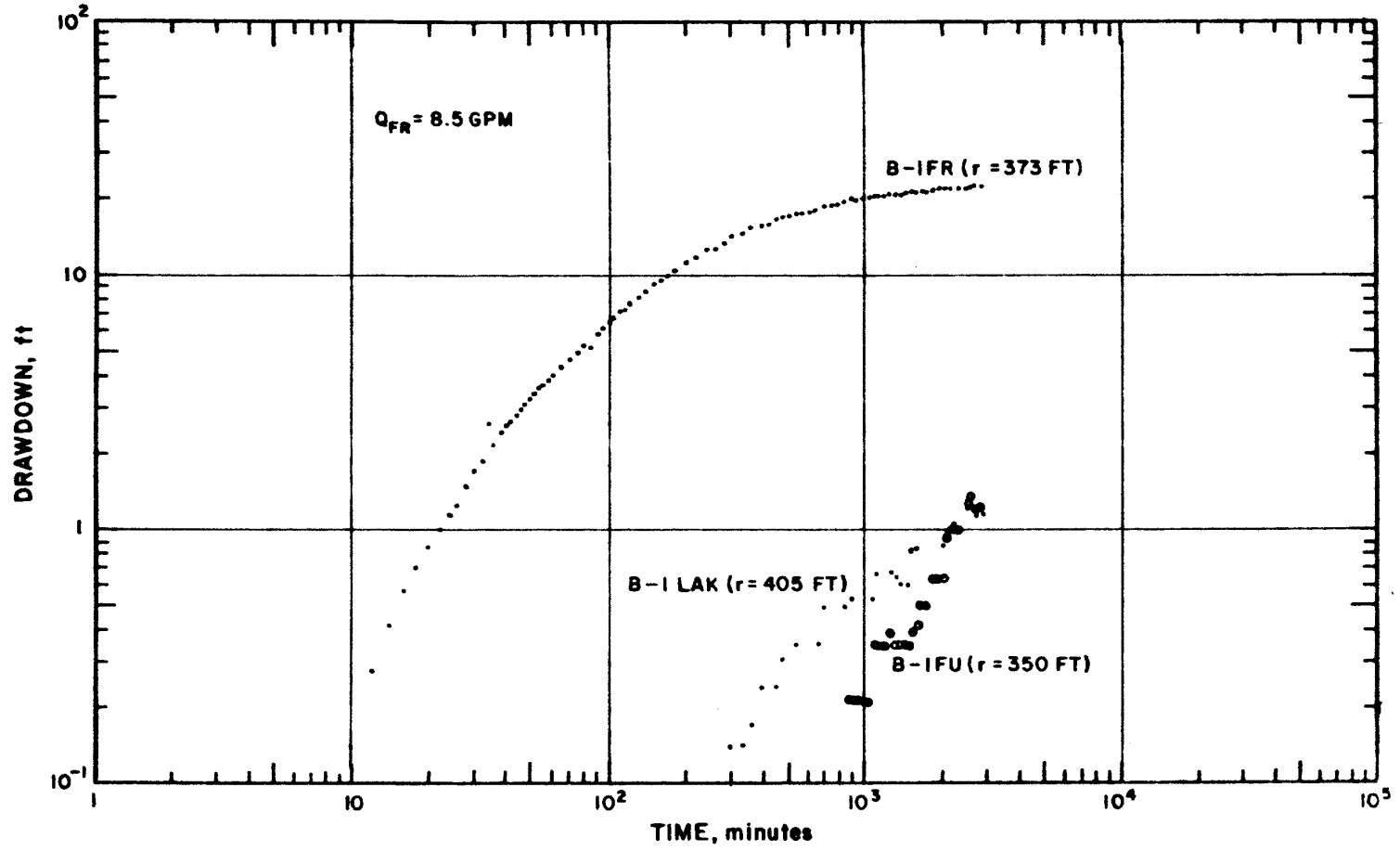


Figure 32: Logarithmic Graphs of Drawdown for B-I Observation Well Group, Fall River Aquifer Test

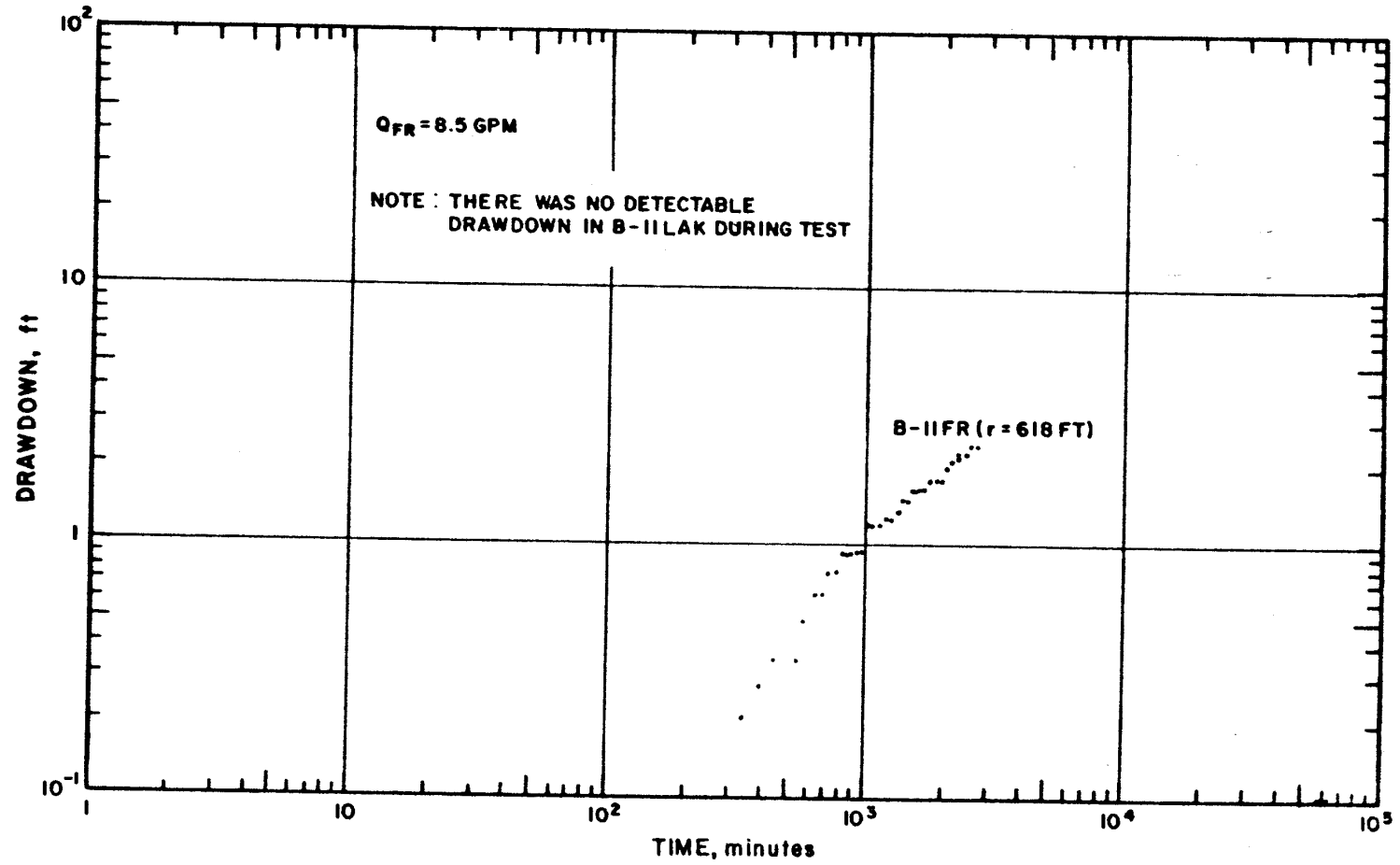


Figure 33: Logarithmic Graphs of Drawdown for B-II Observation Well Group, Fall River Aquifer Test

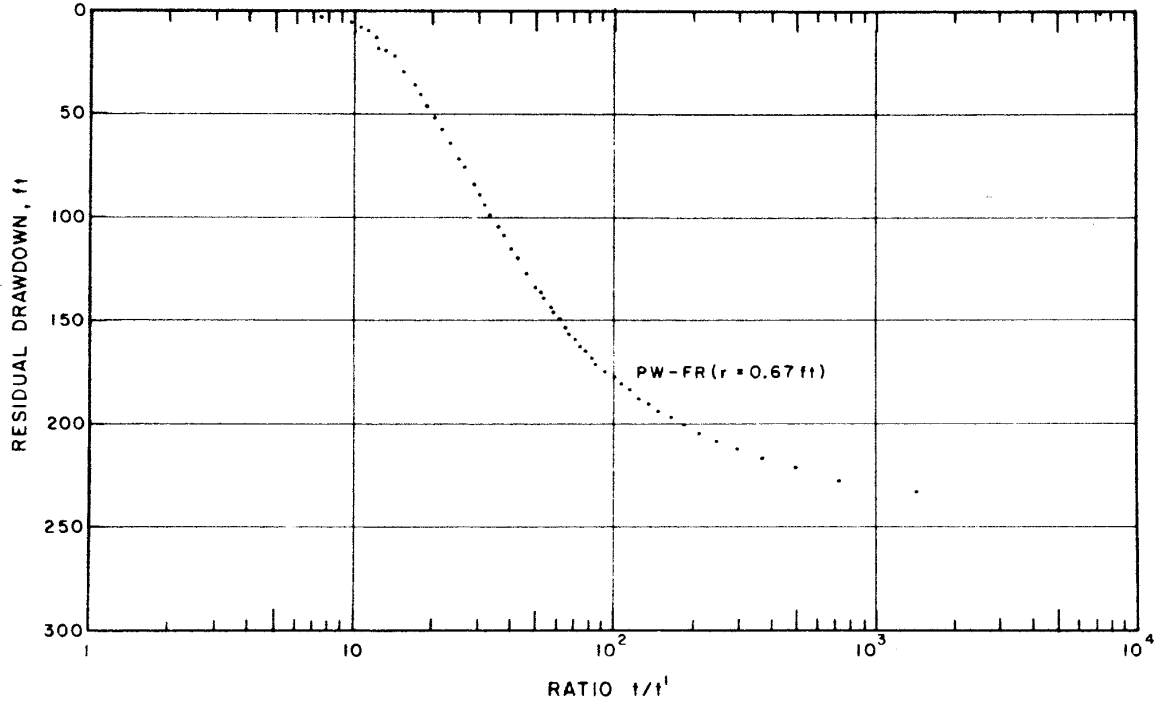


Figure 34: Recovery Graph for Pumped Well, Fall River Aquifer Test



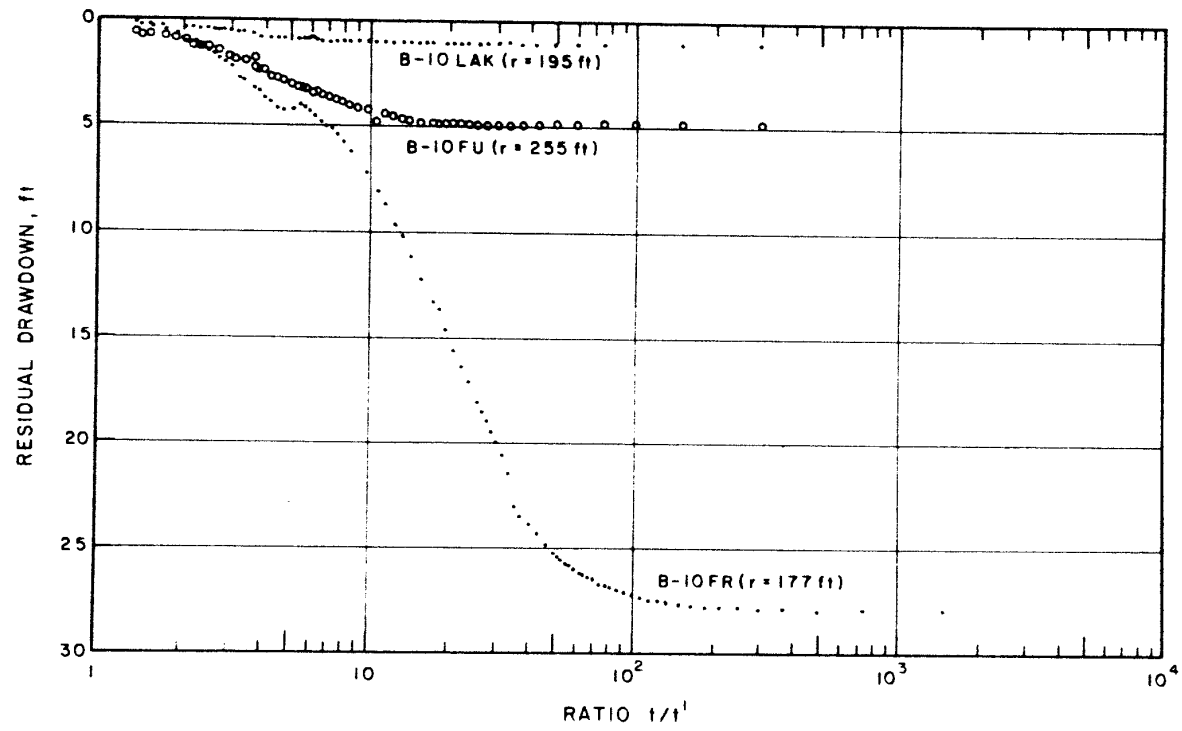


Figure 35: Recovery Graphs for B-10 Observation Well Group, Fall River Aquifer Test

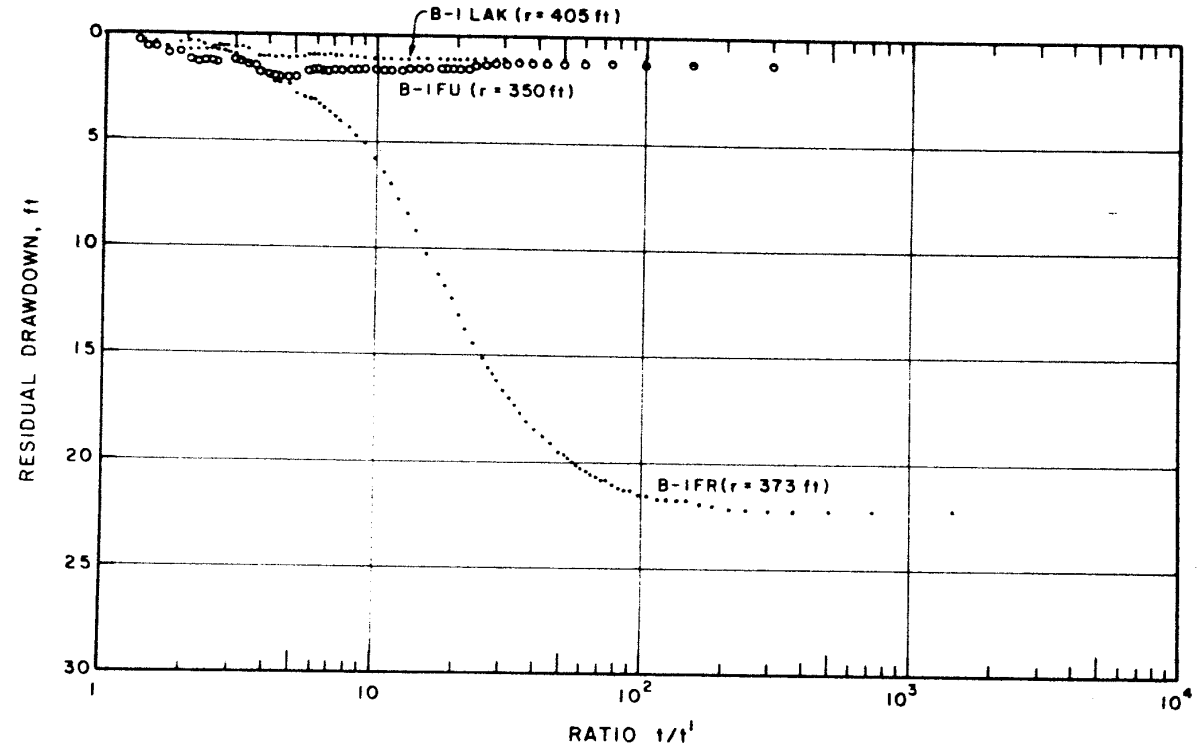


Figure 36: Recovery Graphs for B-1 Observation Well Group, Fall River Aquifer Test

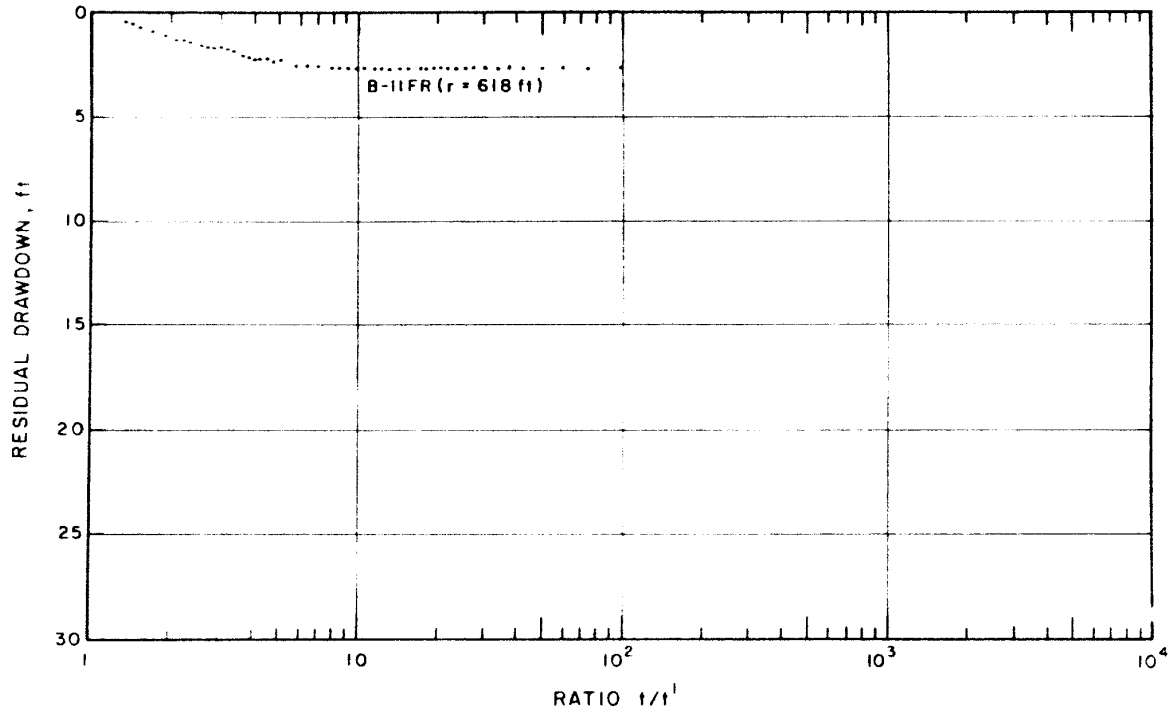


Figure 37 Recovery Graph for B-II Observation Well Group, Fall River Aquifer Test

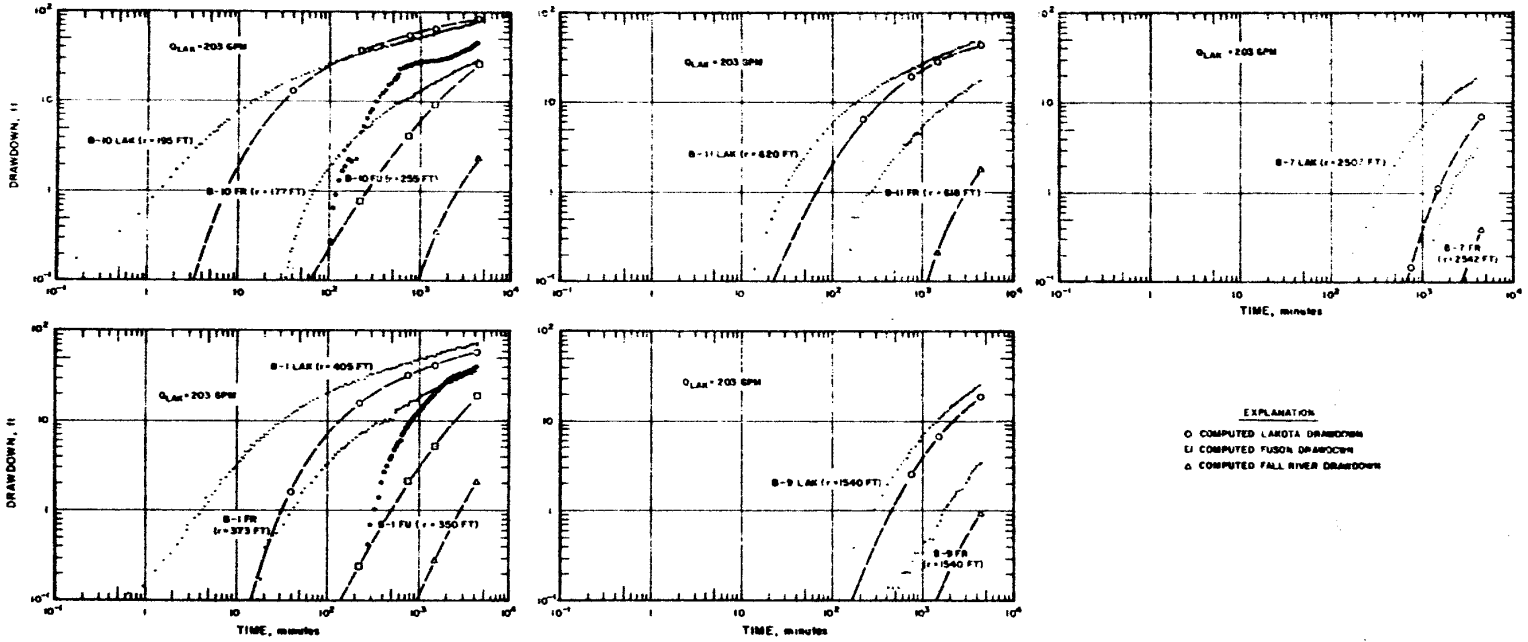


Figure 38 : Results of Initial Lakota Aquifer Test Simulation

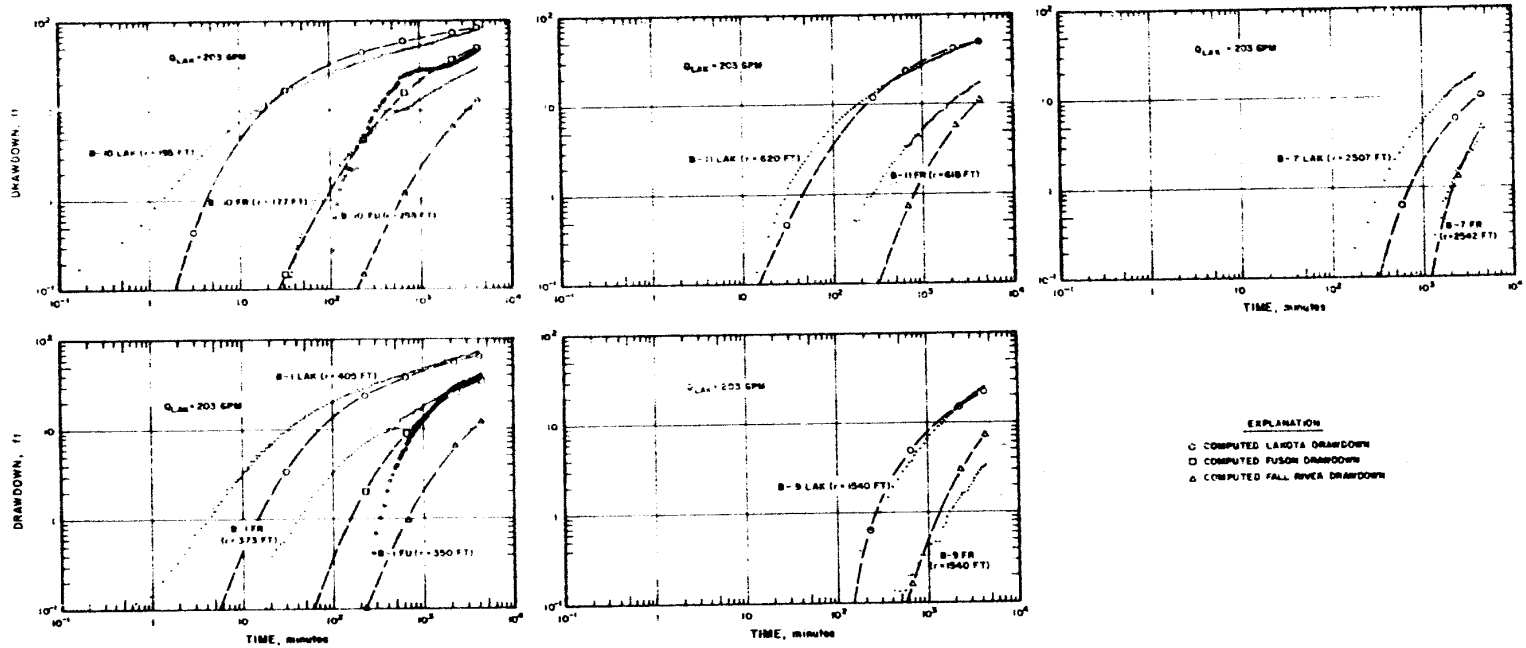
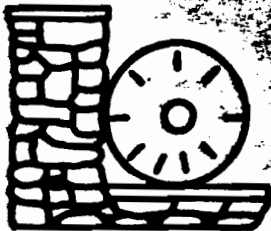


Figure 39 : Results of Final Lakota Aquifer Test Simulation

**WR28-2-520-128**

**HYDROGEOLOGIC INVESTIGATIONS  
AT PROPOSED URANIUM MINE  
NEAR DEWEY, SOUTH DAKOTA**

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Tennessee Valley Authority  
Office of Natural Resources  
Division of Air and Water Resources  
Water Systems Development Branch

HYDROGEOLOGIC INVESTIGATIONS AT  
PROPOSED URANIUM MINE NEAR  
DEWEY, SOUTH DAKOTA

Report No. WR28-2-520-128

Prepared by  
J. Mark Boggs  
Norris, Tennessee  
October 1983

ABSTRACT

The Lakota and Fall River Formations represent aquifers of major importance in the Southern Black Hills Region as well as host rock for uranium ore. An 11-day constant discharge test involving 13 observation wells and numerous private wells was conducted in the Lakota aquifer at TVA's proposed uranium mine near Dewey, South Dakota. The pumping phase of the test was followed by several months of water-level recovery measurements. Results indicate that the test site is located in an area where the Lakota is exceptionally permeable having a transmissivity of 4,400 gpd/ft and a storativity of about  $1 \times 10^{-4}$ . Outside of this locality the Lakota transmissivity decreases substantially due to aquifer thinning and a change to finer-grained sedimentary facies. The drawdown response in the Fall River aquifer was substantially less than that observed during a similar test conducted at TVA's proposed Burdock mine, indicating that the Fuson shale unit lying between the two aquifers is a more effective aquitard in the Dewey area. It is further concluded that the nearby Dewey fault acts as a barrier to horizontal ground-water movement in the Lakota and Fall River aquifers.



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## INTRODUCTION

The following report describes a hydrogeologic test conducted February 1982 at TVA's proposed uranium mine shaft site near Dewey, South Dakota (Figure 1). The Dewey test is one of a series of tests TVA has conducted in aquifer units of the Inyan Kara Group in the southwestern Black Hills area. The purpose of these tests is to obtain sufficient quantitative information about local hydrogeologic conditions to enable prediction of mine depressurization requirements and impacts to local ground-water users.

## HYDROGEOLOGIC ENVIRONMENT

The principal aquifers in the region are the alluvial deposits associated with the Cheyenne River and its major tributaries, the Fall River formation, the Lakota formation, the Sundance formation, and the Pahasapa (or Madison) formation. Except for the alluvium, these aquifers crop out peripherally to the Black Hills where they receive recharge from precipitation. Ground-water movement is in the direction of dip, radially from the central Black Hills. In most instances, ground water in these aquifers is under artesian conditions away from the outcrop area, and water flows at ground surface from numerous wells in the area.

The Fall River and Lakota formations which form the Inyan Kara Group are the most widely used aquifers in the region. The alluvium is used locally as a source of domestic and stock water. The Sundance formation is used near its outcrop area in central and northwestern Fall River County. The Pahasapa (Madison) formation is locally accessible only by very deep wells and is the source for five wells in the city of Edgemont.

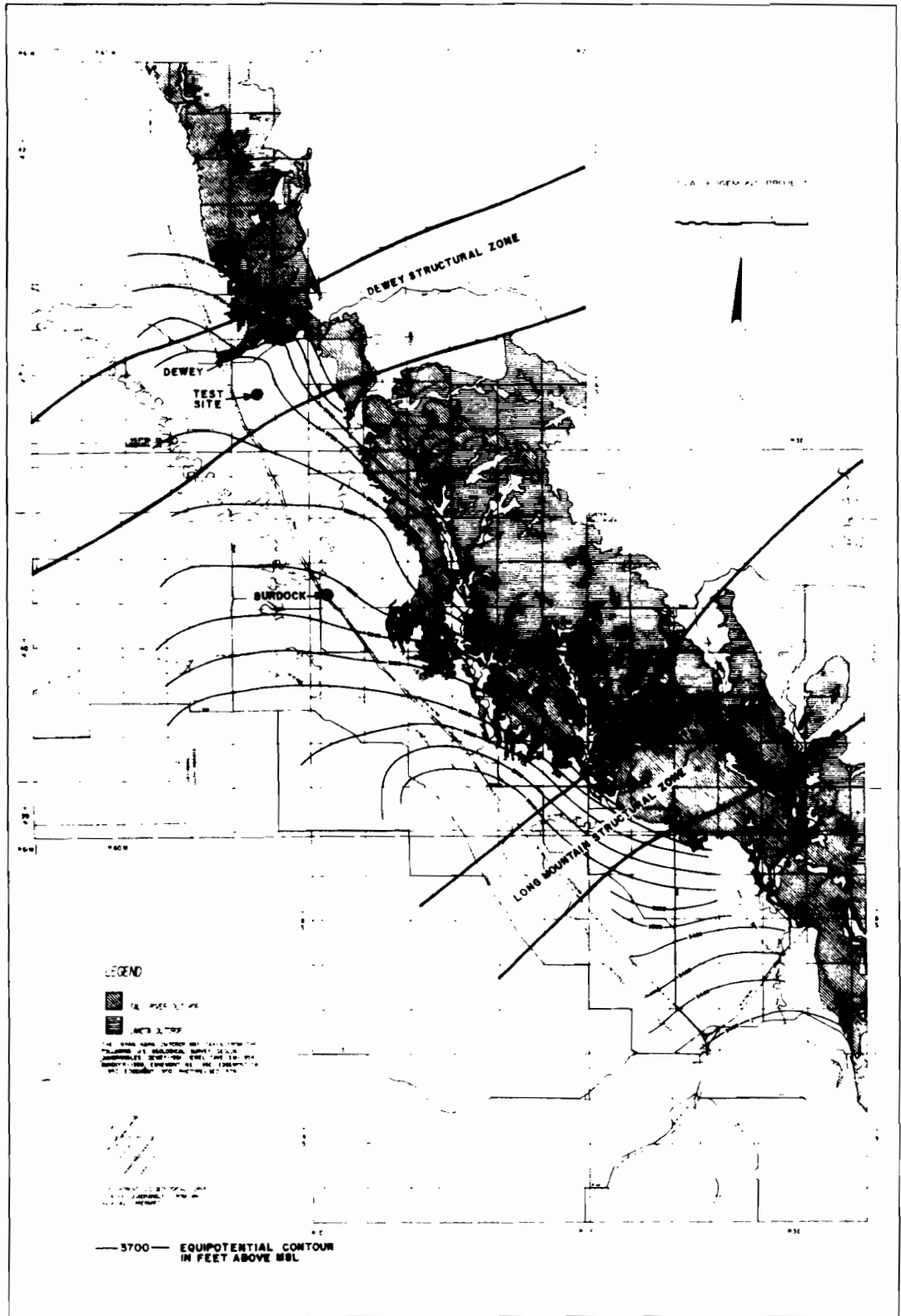


Figure 1: Site Location and Potentiometric Surface Map

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The Fall River and Lakota aquifers are of primary concern because of the potential impact of mine dewatering on the numerous wells developed in these aquifers in the vicinity of the mine. At the proposed mine site, the Fall River consists of approximately 180 feet of interbedded fine-grained sandstone, siltstone and carbonaceous shale. The Fall River aquifer is overlain by approximately 400 feet of the Mowry and Skull Creek shales unit, which act as confining beds. Five domestic and stock-watering wells are known to be developed in the Fall River formation within a four-mile radius of the mine site.

The Fall River formation is underlain by Fuson member of the Lakota formation consisting primarily of siltstone and shale with occasional fine-grained sandstone lenses. Thickness of the Fuson is on the order of 100 feet in the site vicinity. The Fuson acts as a leaky aquitard between the Fall River and Lakota aquifers.

The Chilson member of the Lakota formation is the source for some 30 wells within a four-mile radius of the mine site. It also represents the primary uranium-bearing unit targeted for mining. The Chilson (also referred to as the "Lakota aquifer" in this report) consists of about 120 feet of consolidated to semi-consolidated, fine-to-coarse grained sandstone with interbedded siltstone and shale. It is underlain by the Morrison formation consisting of interbedded shale and fine-grained sandstone. Regionally, the Morrison is not considered an aquifer. Under conditions of ground-water withdrawal from the Chilson, the Morrison is expected to act as an aquitard.

Recharge to the Fall River and Lakota aquifers is believed to occur at their outcrop areas. Gott, et al. (1974), suggest on the basis of geochemical data that recharge to these aquifers may also be derived from the upward movement of ground water along solution collapses and breccia

pipes from the deeper Minnelusa and Pahasapa aquifers. The solution collapse and breccia pipe features lie within the Dewey and Long Mountain structural zones (Figure 1).

Inasmuch as the proposed mine site lies only about one mile south of the Dewey fault trace, one of the primary objectives of the test was to determine the hydrologic significance of the fault and its affect on the propagation of drawdown in the vicinity of the mine during depressurization. Vertical displacement on the major fault generally increases toward the southwest, and is on the order of 200 feet at the point where the fault trace crosses the South Dakota-Wyoming border. Thus, it appears that the Fall River and Lakota aquifers are completely offset by the fault in the site vicinity.

### LAKOTA AQUIFER TEST

#### Design

The shaft site for the Dewey mining area had not been selected at the time the aquifer testing designs were made. The test site was, therefore, located in the general vicinity of the proposed mine site within close proximity to the Dewey fault. The test well was completed to a depth of 804 feet and was screened within the Chilson member of the Lakota Formation. A network of eleven observation wells were constructed along two perpendicular lines intersecting at the pumped well for the purpose investigating hydrologic boundary conditions. One line of wells was oriented normal to the Dewey fault trace, and the other was approximately normal to the aquifer outcrop belt to the east (see Figure 2). Seven of these wells were developed in the Chilson member, three in the Fall River formation,

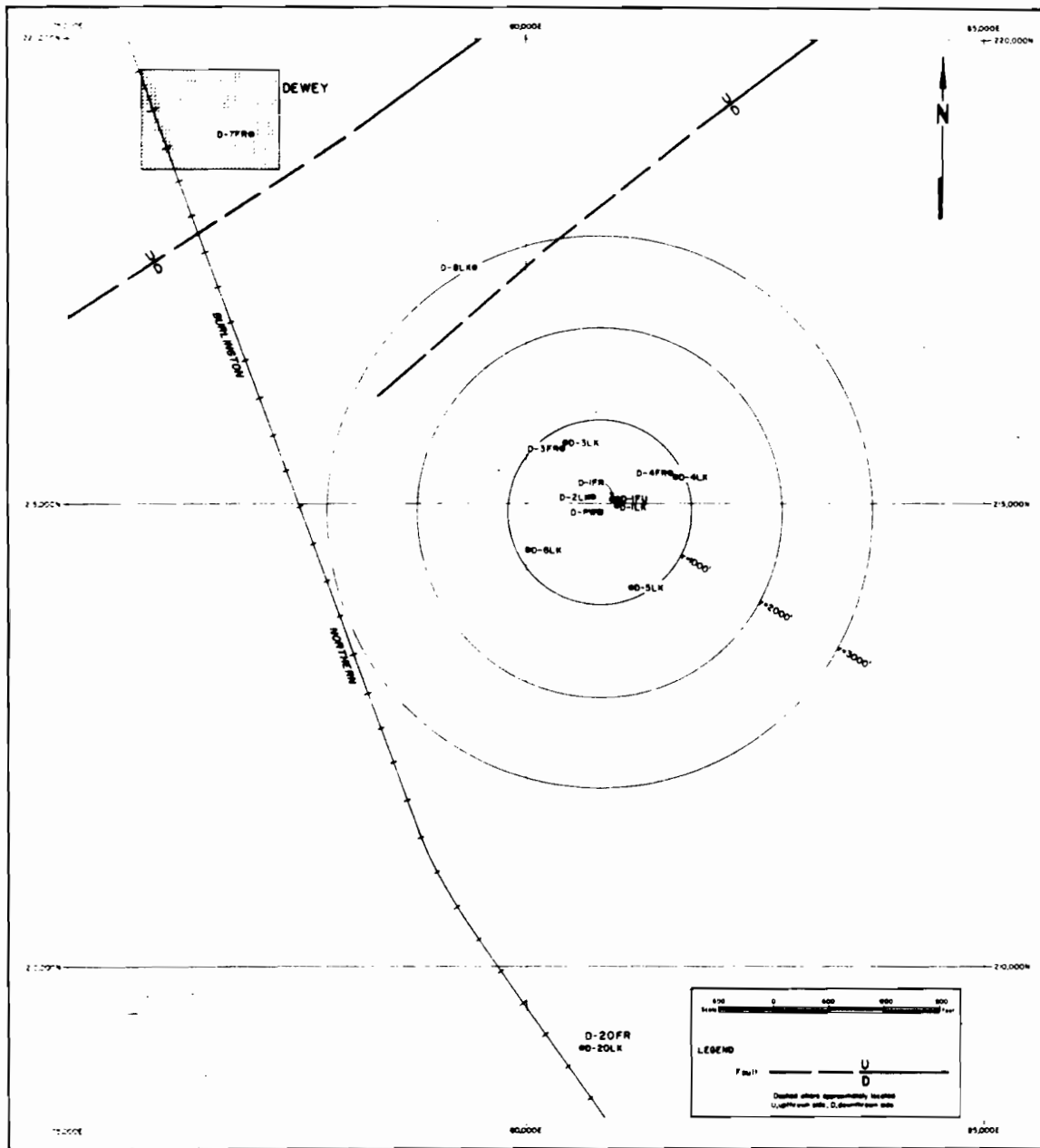


Figure 2: Well Location Map

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and one in the Fuson. Preexisting observation wells BPZ-20LAK and BPZ-20FR (hereafter referred to as D-20LK and D-20FR, respectively) located about one mile south of the test well were also monitored during the test. Construction details for these wells are given in Table 1. In addition, periodic measurements of water level (or well flowrate) were made during the test at all private wells within the test site vicinity.

Based upon preliminary drilling results in the Dewey test site area and experience from the Burdock aquifer tests, it was expected that the Fall River and Lakota aquifers in the Dewey area would respond essentially as a single aquifer system. As a result less emphasis was placed on measurement of the Fuson aquitard properties.

### Procedures

A constant-discharge aquifer test was initiated at 1000 hours on February 16, 1982. Discharge from the well was pumped into an arroyo which ultimately drained into a stock pond located about one mile west of the test site. There was no possibility of recirculation of well discharge water during the test due to the 400+ feet thickness of shale between ground surface and the top of the Fall River aquifer. The well pumping rate was monitored with an in-line flow meter and with an orifice plate and manometer device at the end of the discharge line. The pumping rate varied little during the test ranging from 493 to 503 gpm and averaging 495 gpm. The pumping phase of the test lasted 11 days and was followed by approximately 10 months of recovery measurements. Water level measurements in all wells were made with electric probes. Flow rates associated with offsite private wells were checked with a bucket and stop watch.

TABLE 1. Well Construction Data

| <u>Well No.</u> | <u>Depth (feet)</u> | <u>Casing Diameter (inches)</u> | <u>Depth Interval of Open Borehole or Well Screen (feet)</u> | <u>Distance From Pumped Well (feet)</u> |
|-----------------|---------------------|---------------------------------|--|---|
| D-PW            | 804                 | 10                              | 695-725, 755-800   | --                                      |
| D-1LK           | 800                 | 4                               | 712-800  | 189                                     |
| D-1FU           | 620                 | 4                               | 609-620  | 229                                     |
| D-1FR           | 580                 | 4                               | 504-580  | 186                                     |
| D-2LK           | 800                 | 4                               | 692-800  | 191                                     |
| D-3LK           | 800                 | 4                               | 715-800  | 851                                     |
| D-3FR           | 590                 | 4                               | 505-590  | 810                                     |
| D-4LK           | 780                 | 4                               | 714-780  | 905                                     |
| D-4FR           | 580                 | 4                               | 503-580  | 879                                     |
| D-5LK           | 835                 | 4                               | 735-835  | 872                                     |
| D-6LK           | 810                 | 4                               | 715-810  | 890                                     |
| D-7FR           | 120                 | 4                               | 119-120  | 5610                                    |
| D-8LK           | 750                 | 4                               | 650-750  | 2785                                    |
| D-20LK          | 860                 | 4                               | 798-860  | 5700                                    |
| D-20FR          | 672                 | 1                               | 671-672  | 5700                                    |



### Analysis

Semilogarithmic graphs of drawdown ( $s$ ) versus time ( $t$ ) for the pumped well and observation wells are given in Appendix A. The drawdown trends in wells D-PW, D-1LK and D-2LK are essentially the same, i.e., there is a period of roughly linear drawdown during the first 1000 minutes of the test, followed by a gradual increase in the rate of drawdown during the remainder of the test. The remaining Lakota wells exhibit  $s$ - $t$  curves which have a continuous increase in slope throughout the test without stabilizing to a linear drawdown trend. A slight increase in hydrostatic water level was observed during the early period of the test in the Fall River and Fuson wells. This seemingly paradoxical behavior, known as the Noordbergum effect, is due to a transfer of stress from the pumped aquifer to the adjacent aquitards and aquifers (Gambolati, 1974). Drawdowns observed in the Fall River and Fuson wells were much less than those recorded during a similar test conducted near Burdock (Boggs and Jenkins, 1980). The Jacob straight-line method (Walton, 1970) was applied to the semilog graphs for the Lakota wells to obtain the values of transmissivity ( $T$ ) and storativity ( $S$ ) presented in Table 2. In the case of the closer observation wells, two straight-line data fits were possible: one using the early data and another using the late data. Only the late data for the more distant observation wells were analyzed by this method.

Logarithmic  $s$ - $t$  graphs for all test wells are given in Appendix B. Theis curve-matching techniques (Walton, 1970) were applied to the Lakota aquifer curves to obtain the  $T$  and  $S$  estimates presented in Table 2. Due to the somewhat unusual shape of the  $s$ - $t$  response curves, the only curve-match solutions possible were those using the early data.

TABLE 2. Computed Lakota Aquifer Properties

| Well   | r<br>(ft) | Jacob Method |        |       |          |       | Theis Method |        |
|--------|-----------|--------------|--------|-------|----------|-------|--------------|--------|
|        |           | Drawdown     |        |       | Recovery |       | $T_e$        | $S_e$  |
|        |           | $T_e$        | $S_e$  | $T_1$ | $T_e$    | $T_1$ |              |        |
| D-PW   | 0.67      | 4400         | --     | 890   | 4890     | 680   | --           | --     |
| D-1LK  | 189       | 5280         | 3.E-05 | 890   | 4890     | 650   | 5210         | 3.E-05 |
| D-2LK  | 191       | 4400         | 3.E-04 | 910   | 4710     | 650   | 4090         | 2.E-04 |
| D-3LK  | 851       | --           | --     | 920   | --       | 670   | 6900         | 7.E-05 |
| D-4LK  | 905       | --           | --     | 900   | --       | 680   | 4090         | 8.E-05 |
| D-5LK  | 872       | --           | --     | 900   | --       | 670   | 4410         | 7.E-05 |
| D-6LK  | 890       | --           | --     | 900   | --       | 650   | 6030         | 8.E-05 |
| D-8LK  | 2785      | --           | --     | 940   | --       | 680   | 3180         | 5.E-05 |
| D-20LK | 5700      | --           | --     | --    | --       | 680   | 1400         | 3.E-05 |

Note: Transmissivity ( $T_e$ ,  $T_1$ ) in units of gpd/ft.

A semilog plot of the final drawdown in each Lakota well versus its radial distance from the pumped well is shown in Figure 3. The Jacob straight-line method was applied to this plot to obtain T and S values of 4400 gpd/ft and  $10^{-6}$ , respectively, for the Lakota aquifer. The storativity value computed by this method is considered highly unreliable since it is two orders of magnitude lower than expected.

Water level recovery data for all wells are presented in Appendix C. Data are plotted as semilog graphs of residual drawdown versus  $t/t'$  (ratio of time since pumping started to time since pumping stopped). The Lakota graphs were analyzed using the Jacob method. Again, two straight-line fits are possible for the closer Lakota wells. Both are given in Table 2.

Fuson aquitard properties were estimated from the D-1 well group data using the ratio method (Neuman and Witherspoon, 1973). The vertical hydraulic conductivity of the aquitard ( $K'_v$ ) is computed to be approximately  $2 \times 10^{-4}$  ft/d based on the average of several computed  $K'_v$  during the interval between 1800 and 5000 minutes. For purposes of the analysis, the specific storativity ( $S'_s$ ) of the aquitard was assumed to be approximately equal to that computed for the Lakota aquifer (about  $7 \times 10^{-7}$  ft<sup>-1</sup>).

### Interpretation

The T estimates obtained from all methods using the early drawdown and recovery data are in reasonably good agreement. Values range from 3180 to 6900 gpd/ft and average approximately 4800 gpd/ft. The T of 4400 gpd/ft derived from the distance drawdown analysis is also consistent with the early T estimates. These values are believed to represent the transmissivity of the Lakota aquifer within the immediate vicinity of the test

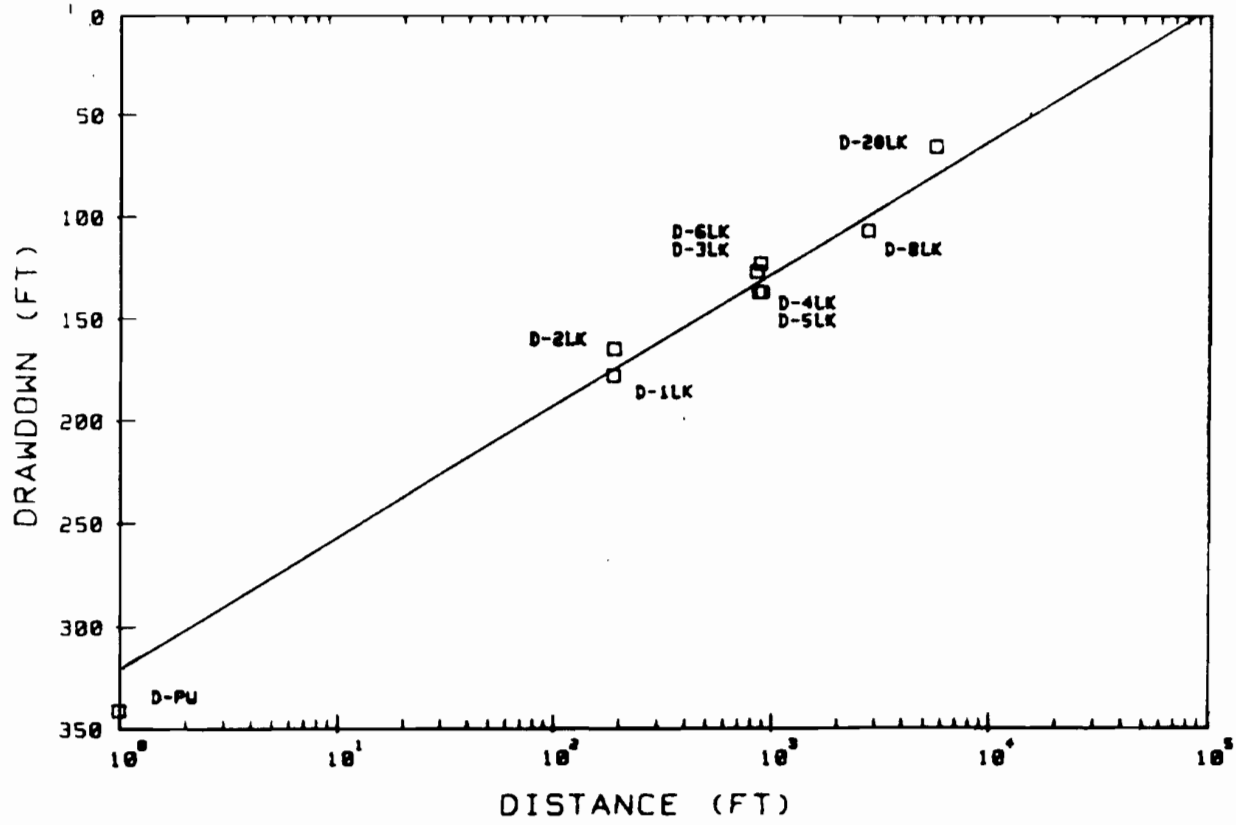


FIGURE 3. DISTANCE-DRAWDOWN GRAPH

site, and are consistent with the physical characteristics of the aquifer materials within this area. The T values computed from the late drawdown data, although consistent from well to well, are not reliable since the rate of drawdown during the later stage of the test never stabilized to the linear or ideal Theis-curve trend. The late recovery data provide the best estimates of the regional or long-term transmissivity of the Lakota aquifer in the Dewey region because of the long duration of this phase of the test.

In general, drawdown response in the pumped well and closer observation wells is characterized by a period of approximately linear drawdown during the first 1000 minutes of the test, followed by a steadily increasing rate of drawdown until the end of the test. The recovery data reflects the same sort of trend. The late response may be interpreted as either the effect of barrier boundary conditions or a decrease in transmissivity with distance from the test site or both.

Most of the available hydrogeologic information indicates that the Dewey fault acts as a barrier to horizontal ground-water movement in the Inyan Kara aquifers. Vertical displacement along the Dewey fault is on the order of 200 feet in the test site vicinity causing the complete separation of the Lakota aquifer on either side of the fault. Despite the geochemical evidence of Gott, et al. (1974), that the fault may act as conduit for upward circulation of ground water from deeper aquifers to the Inyan Kara Group, a recharge condition is not reflected in the potentiometric surface configuration in the fault zone (Figure 1) or in the test results. A reduction in the rate of drawdown would be expected in the s-t graphs for observation wells closest to the fault if significant recharge occurred in the fault zone. Instead the opposite response is observed in the test data. The s-t curve for well D-8LK (the closest observation well to the fault)

exhibits the steepest slope during the late stage of the test, supporting the idea that the fault is a hydrogeologic barrier. Upward recharge may occur in the fault zone but at relatively low rates. Consequently, the fault does not behave as a recharge boundary.

### Computer Simulations

A computer ground-water model of the Dewey region was developed to aid in interpreting the test results and refining aquifer parameters. A three-dimensional ground-water flow code developed by Trescott (1975) was used for the simulations. The Inyan Kara is conceptualized as a three-layer aquifer system consisting of the Lakota (Chilson) aquifer, the Fuson aquitard and the Fall River aquifer, with model layers having uniform thicknesses of 120, 100, and 180 feet, respectively. Impervious boundaries are set above the Fall River layer and below the Lakota layer to represent the relatively impermeable shales which bound the Inyan Kara Group. The model area and finite-difference grid are shown in Figure 4. The outcrop area of the Inyan Kara represents the eastern limit of the modeled region. The remaining three sides of the model are set at sufficient distances from the test pumping well to eliminate the possibility of artificial boundary effects in model simulations. The Dewey fault zone was treated as a barrier boundary.

Simulations were made using two basic conceptual models of the Inyan Kara aquifer system to determine which model best represented observed responses during the Dewey test. For case I, uniform T and S values of 4,400 gpd/ft and  $1 \times 10^{-4}$ , respectively were assigned to the Lakota aquifer. A uniform T was used for this case despite evidence of a much lower transmissivity outside of the immediate test site in order to determine

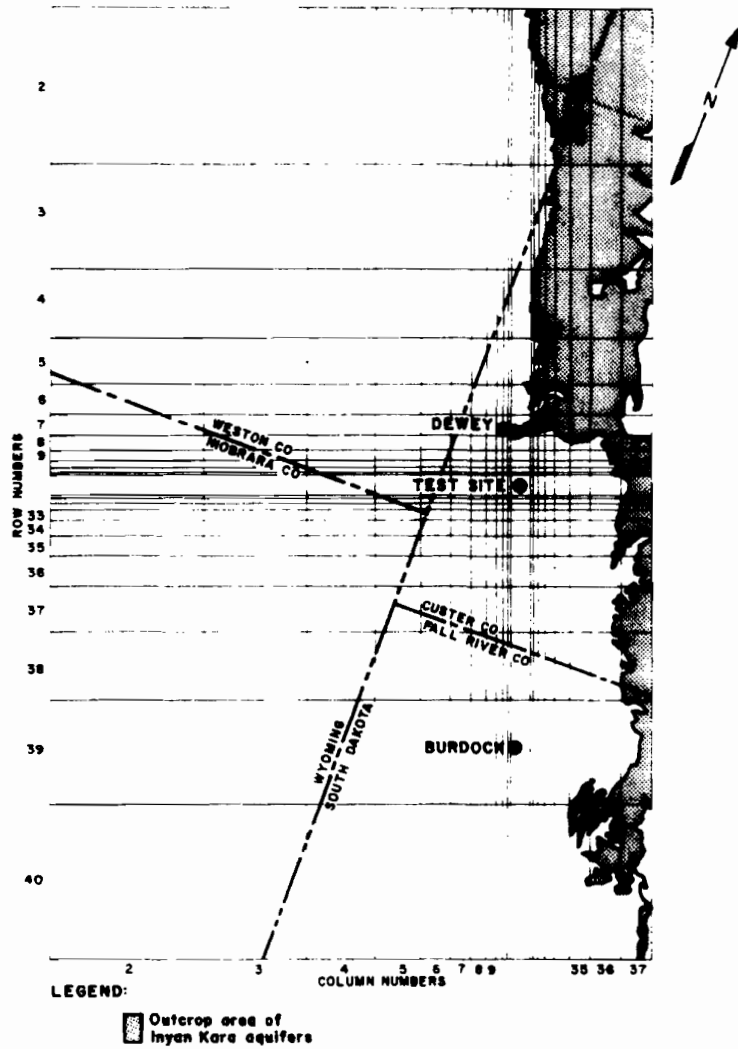


Figure 4: Ground-Water Model Grid

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whether the fault alone could account for late drawdown trends. The Fuson aquitard was assigned a uniform  $K'_v$  of  $10^{-4}$  ft/d. The Fall River aquifer was represented by uniform T and S values of 400 gpd/ft and  $10^{-4}$  respectively, based on the results of the Burdock tests (Boggs and Jenkins, 1980). A simulation was then made of the 11-day Dewey aquifer test using the average pumping rate of 495 gpm in an attempt to reproduce the test results. A comparison of computed and observed s-t graphs for the Lakota observation wells is shown in Figure 5. Clearly, the barrier boundary condition created by the fault does not fully account for the observed increase in drawdown rate during the latter part of the test.

In Case II, the model was modified to account for the suspected spatial variability of transmissivity in the Lakota aquifer. Geologic evidence indicates that the test site is located in an area where the Lakota is composed of an exceptionally thick coarse-grained sandstone. Outside of this locality the aquifer becomes thinner and its composition changes to finer-grained sedimentary facies. These changes are particularly evident in the area east of the site. The test results indicate a local T in the immediate site area of about 4,400 gpd/ft and a regional average of about 670 gpd/ft. These T estimates were used along with areal variations in the sandstone-shale composition of the Lakota aquifer in the site vicinity to arrive at the T distribution shown in Figure 6. Exploration borehole geophysical logs were used to estimate the relative amounts of sandstone and shale in the Lakota across the site area. The horizontal hydraulic conductivity of the sandstone is estimated at approximately  $5.7 \times 10^{-5}$  ft/sec based upon the near-field T estimate of 4,400 gpd/ft, an aquifer thickness of 120 feet, and the assumption that the aquifer in the immediate vicinity of the test well and closest observation wells is essentially all sandstone. The



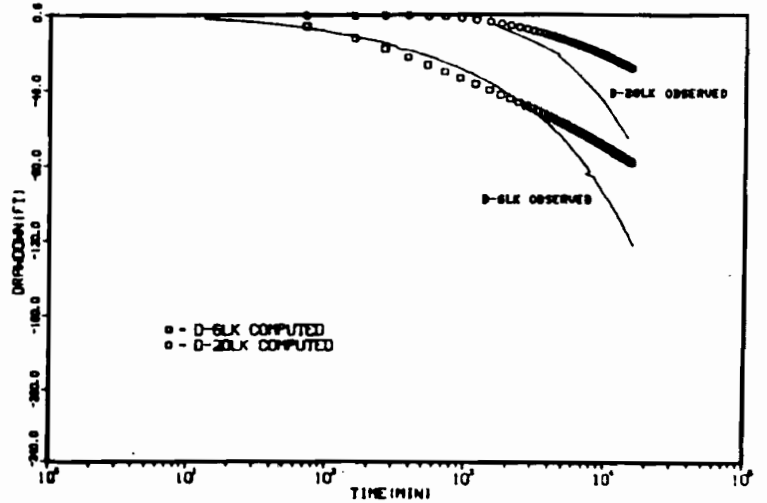
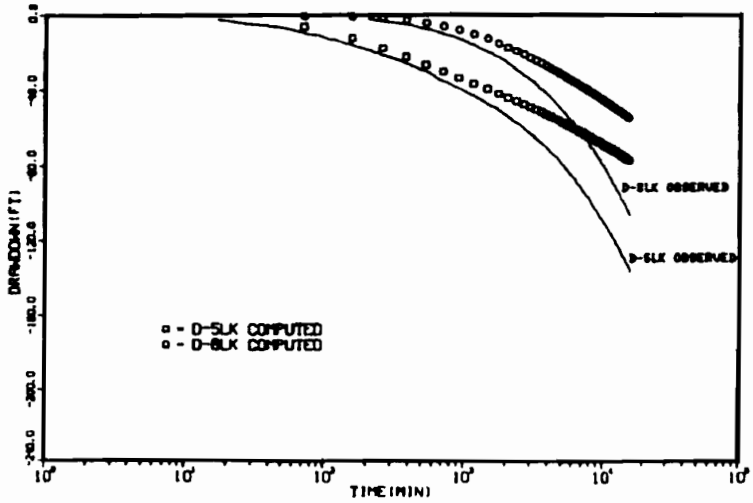
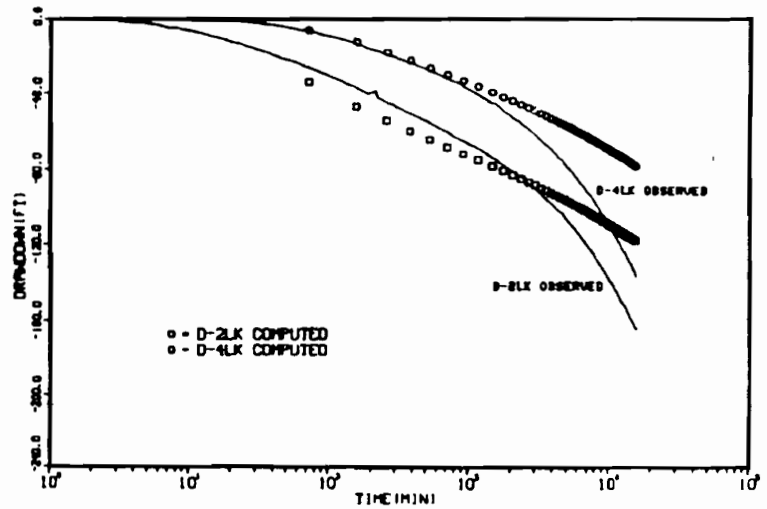
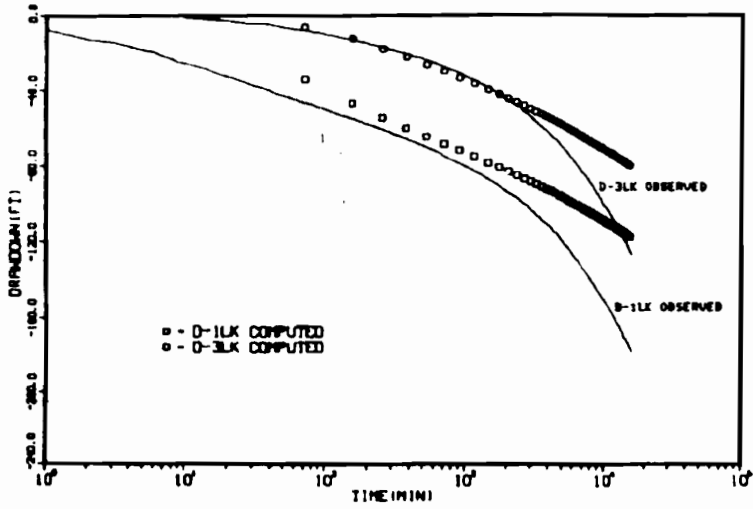


Figure 5. Comparison of Observed and Computed Drawdown, Case I

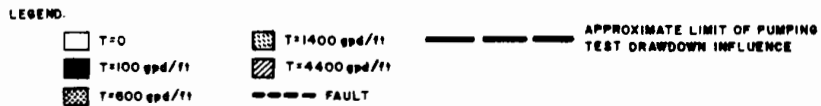
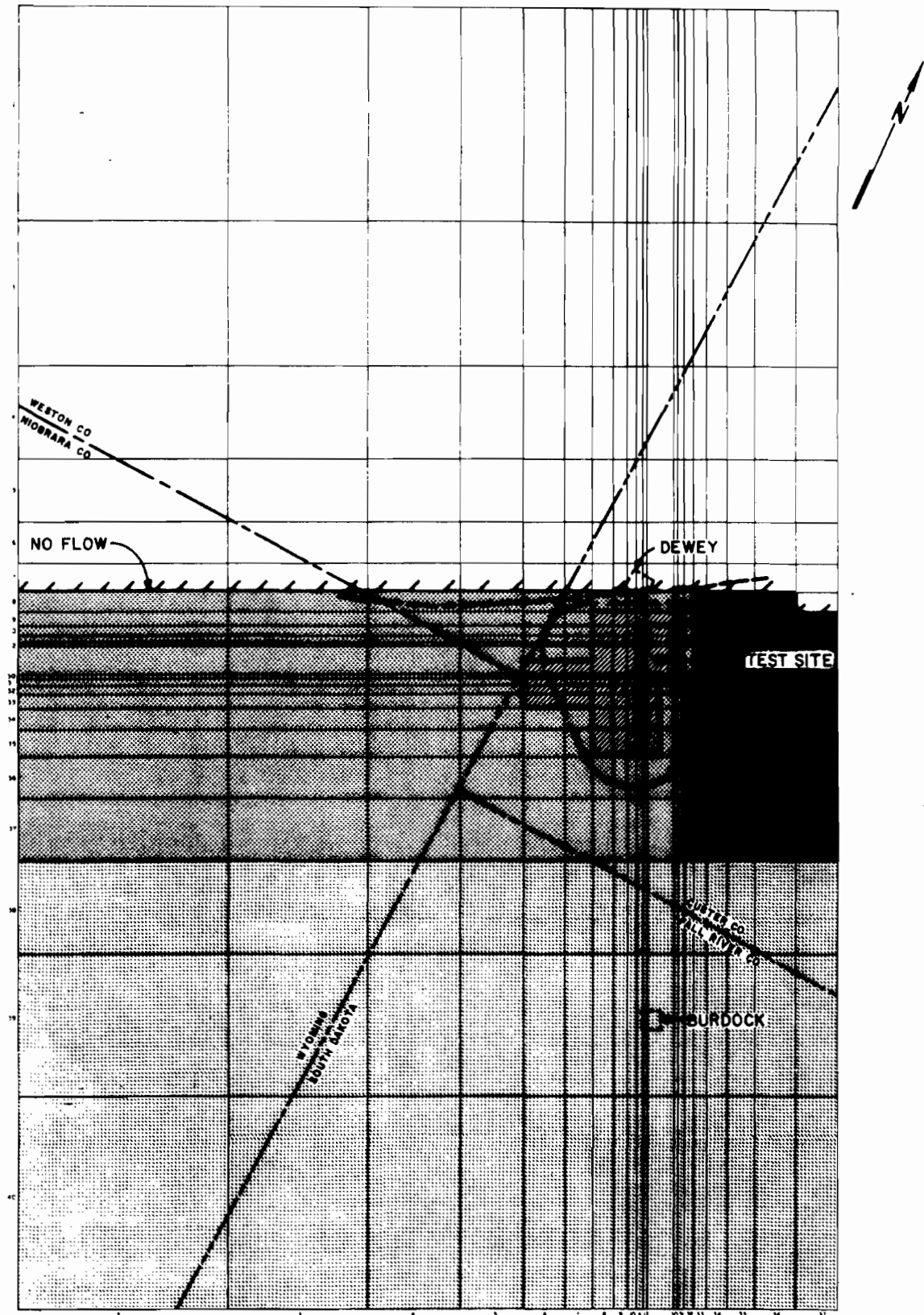


Figure 6: Transmissivity Distribution, Case II

WR28-2-520-128.6

horizontal conductivity of the shale is estimated to be about  $10^{-8}$  ft/sec assuming (1) the measured vertical conductivity of the Fuson shale is also representative of shale in the Lakota aquifer and (2) the ratio of horizontal to vertical conductivity is about 10:1. Given the estimated horizontal conductivities for the sandstone and shale, a representative average conductivity was computed for areas having similar aquifer sandstone-shale ratios. The representative average conductivity was computed from the geometric mean of the conductivity samples as suggested by Bouwer (1969). The transmissivity of 1,400 gpd/ft assigned to the southern portion of the model is based on results of the Burdock aquifer test. Note that although an attempt was made to assign realistic transmissivity values to the entire model region, model simulation results are mainly affected by the transmissivity distribution within the observed limits of influence of the 11-day aquifer test as indicated in Figure 6. Outside of this region the model is relatively insensitive to the assigned T values.

The Case II simulation results are shown in Figure 7. The agreement between the computed and observed drawdown trends in the Lakota wells is quite good overall. At least part of the discrepancy between observed and computed responses in these units is due to the fact that computed hydraulic heads are average values over the thickness of the aquifer or aquitard layer.

The observed drawdown trends could, perhaps, be reproduced using some alternative T distribution without the barrier boundary condition assumed for the Dewey fault. However, if the fault did not represent a barrier, substantial pressure changes should have been observed during the test in the private Lakota wells located north of the fault. These wells are located at approximately the same radial distance as observation well

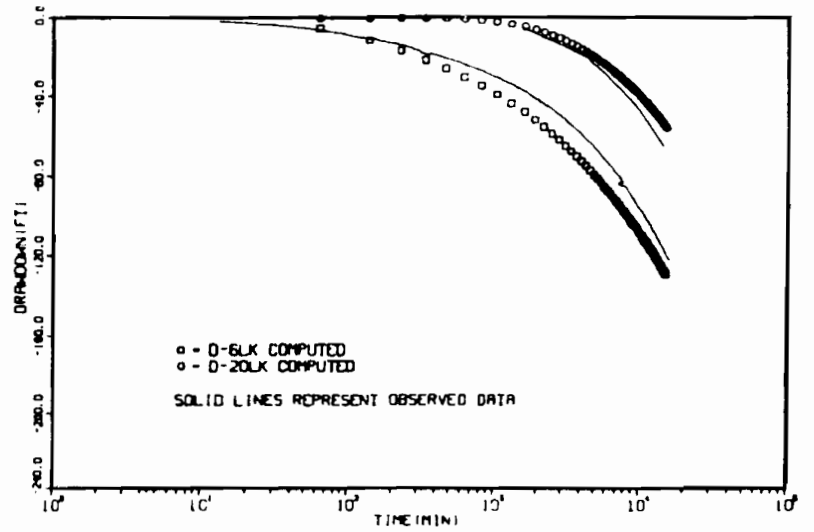
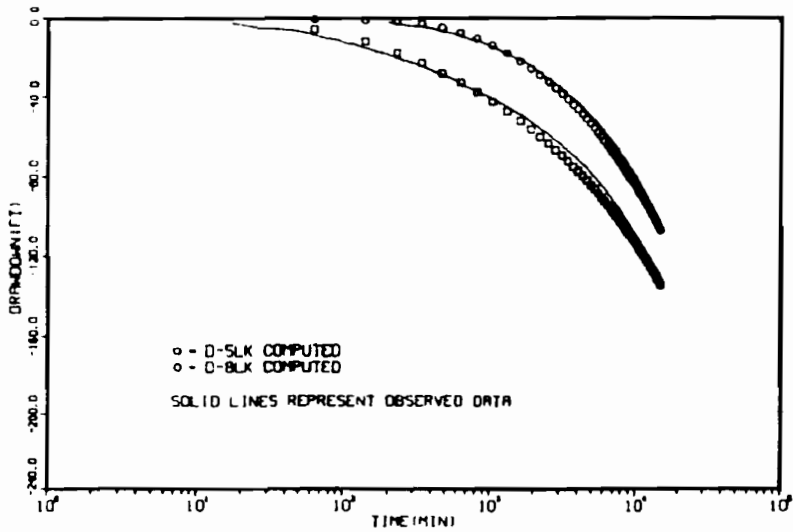
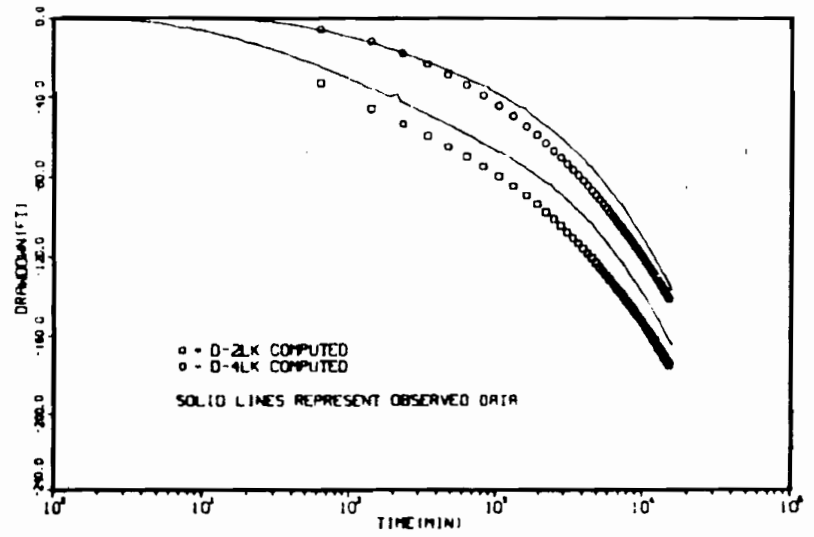
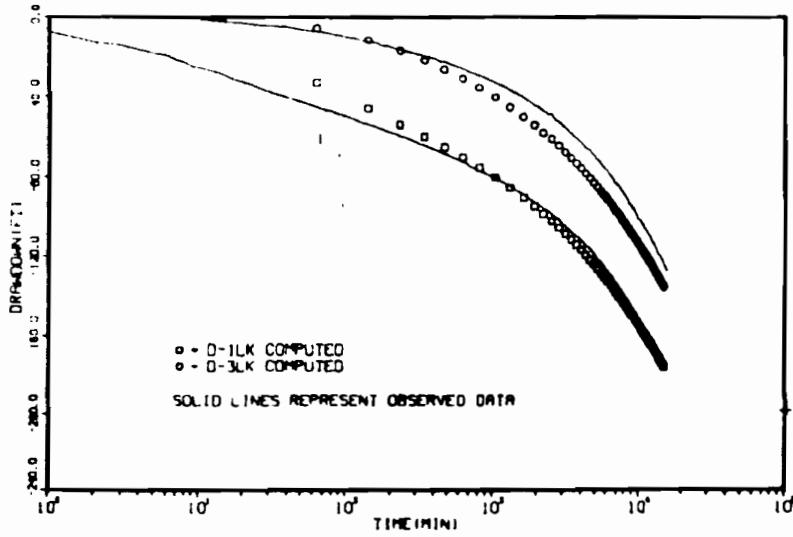


Figure 7. Comparison of Observed and Computed Drawdown, Case II

D-20LK which exhibited 66 feet of drawdown at the end of the test. As no drawdown occurred in these wells, it is concluded that the Dewey fault represents a hydrogeologic barrier.

The Case II simulation results support the concept of the Lakota as a patchy aquifer of relatively low-transmissivity overall but having within it localized zones of substantially higher transmissivity. The proposed mine site lies within one of these high transmissivity localities. Although the T distribution used in the Case II model is based upon reasonable assumptions, it is considered only an approximation of actual conditions in the test site area. Nevertheless, this approximation is adequate for assessing long-term mine depressurization impacts. The significance of the Case II model result is that it provides an interpretation of the test results which is consistent with what is known or suspected about the hydrogeologic conditions in the site region.

### CONCLUSIONS

Hydrogeologic investigations in the Dewey area indicate that the proposed mine site lies within an area where the Lakota Formation is composed of relatively thick permeable sandstone. The transmissivity of the Lakota aquifer in this locality is estimated to be approximately 4,400 gpd/ft. Storativity of the aquifer is about  $10^{-4}$ . Outside of this area the Lakota transmissivity decreases substantially. The variation in transmissivity over the region is consistent with geologic evidence of thinning of the Lakota sandstone away from the test site and a change to finer-grained sand and shale facies. The significance of this condition is that long-term mine depressurization rates and drawdown response in the Dewey vicinity will be

governed by the lower transmissivity material. As a result, dewatering rates will be lower and the areal extent of drawdown impacts smaller than if the higher transmissivity prevailed.

There is evidence that hydraulic communication between the Fall River and Lakota aquifers occurred during the Dewey test. However, the degree of interconnection between these units is substantially less than that observed at the Burdock test site. The vertical hydraulic conductivity of the intervening Fuson aquitard estimated from the Dewey test data is approximately  $10^{-4}$  ft/d. This value is about an order of magnitude lower than the estimate obtained at Burdock. The difference is somewhat surprising in that the Fuson aquitard is thinner in the Dewey area than at Burdock. A possible explanation may be that the direct avenues of hydraulic communication (e.g., numerous open pre-TVA exploration boreholes) believed to exist at Burdock, are not present in the Dewey area.

Evaluation of the drawdown responses recorded in test wells and private wells during the aquifer test and review of existing subsurface geologic data indicates that the Dewey fault zone acts as a hydrogeologic barrier to horizontal ground-water movement between the Inyan Kara aquifers located on opposite sides of the fault zone. Some upward vertical recharge to the Inyan Kara may occur in the fault zone as suggested by Gott, et al. (1968). However, rate of recharge from this source must be relatively small, otherwise recharge effects would be apparent in the aquifer test results and in the configuration of the steady-state potentiometric surface. It is expected that the fault will significantly reduce mining drawdown impacts on ground-water supplies located north of the fault zone.

3. The model should be calibrated by adjustment of hydraulic parameters to reproduce the existing steady-state potentiometric surface shown in Figure 1. The hydraulic properties for the Inyan Kara units measured at the Dewey and Burdock test sites should be held constant in the calibration process, while parameter adjustments are made in other areas to obtain a reasonable match between the computed and observed potentiometric levels. An estimate of net ground-water recharge can be obtained from the calibrated model by assigning observed potentiometric head values to the model nodes which lie within the aquifer recharge (outcrop) area. The aquifer recharge fluxes may be incorporated directly into the model to more accurately represent drawdown conditions in the outcrop areas during mine depressurization simulations.

4. Significant pumping stresses on the Inyan Kara aquifers other than the TVA mining operations should be identified and incorporated into the model.

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FIGURE A-1: DRAWDOWN GRAPH FOR WELL D-PW

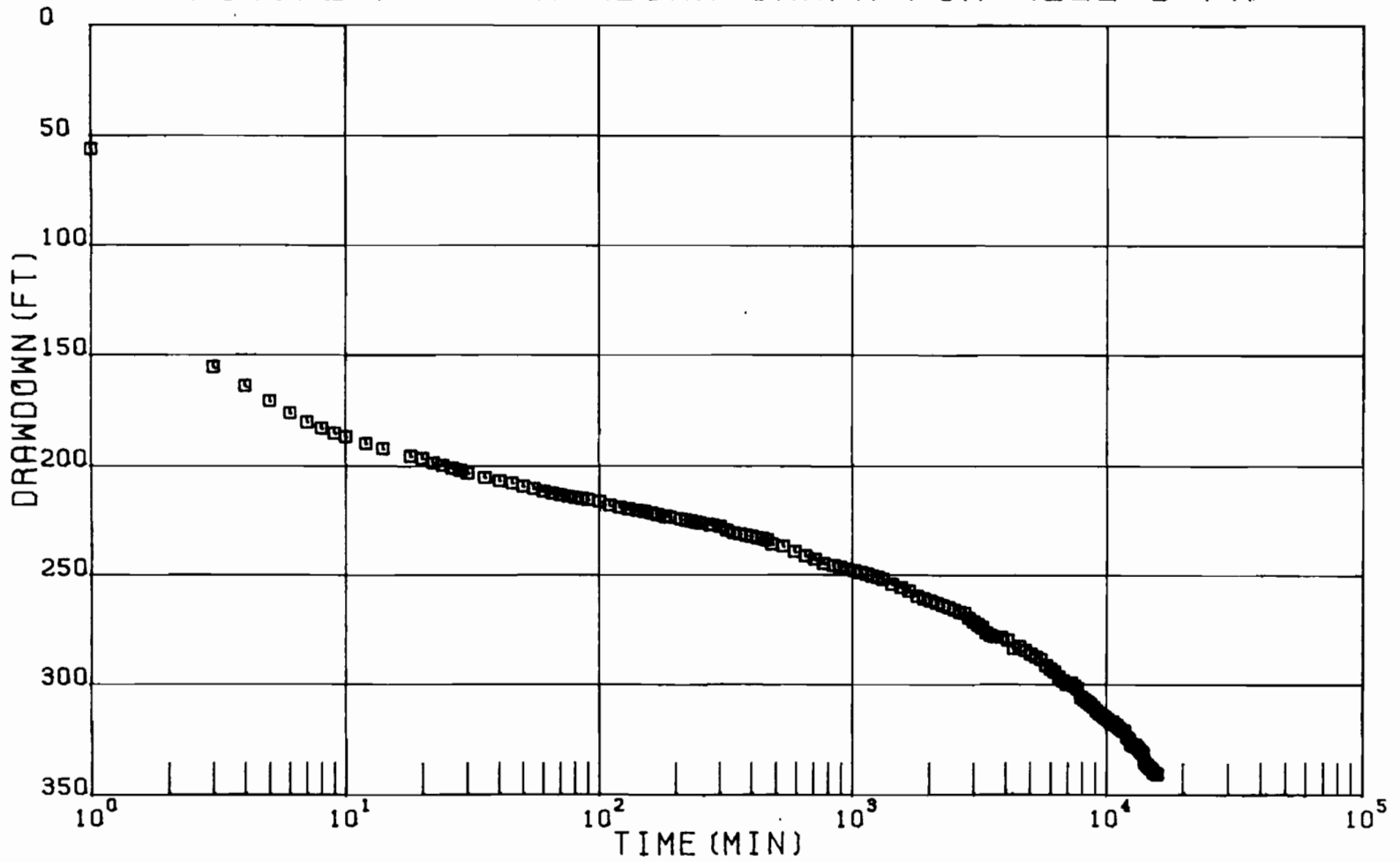


FIGURE A-2: DRAWDOWN GRAPH FOR D-1 WELL GROUP

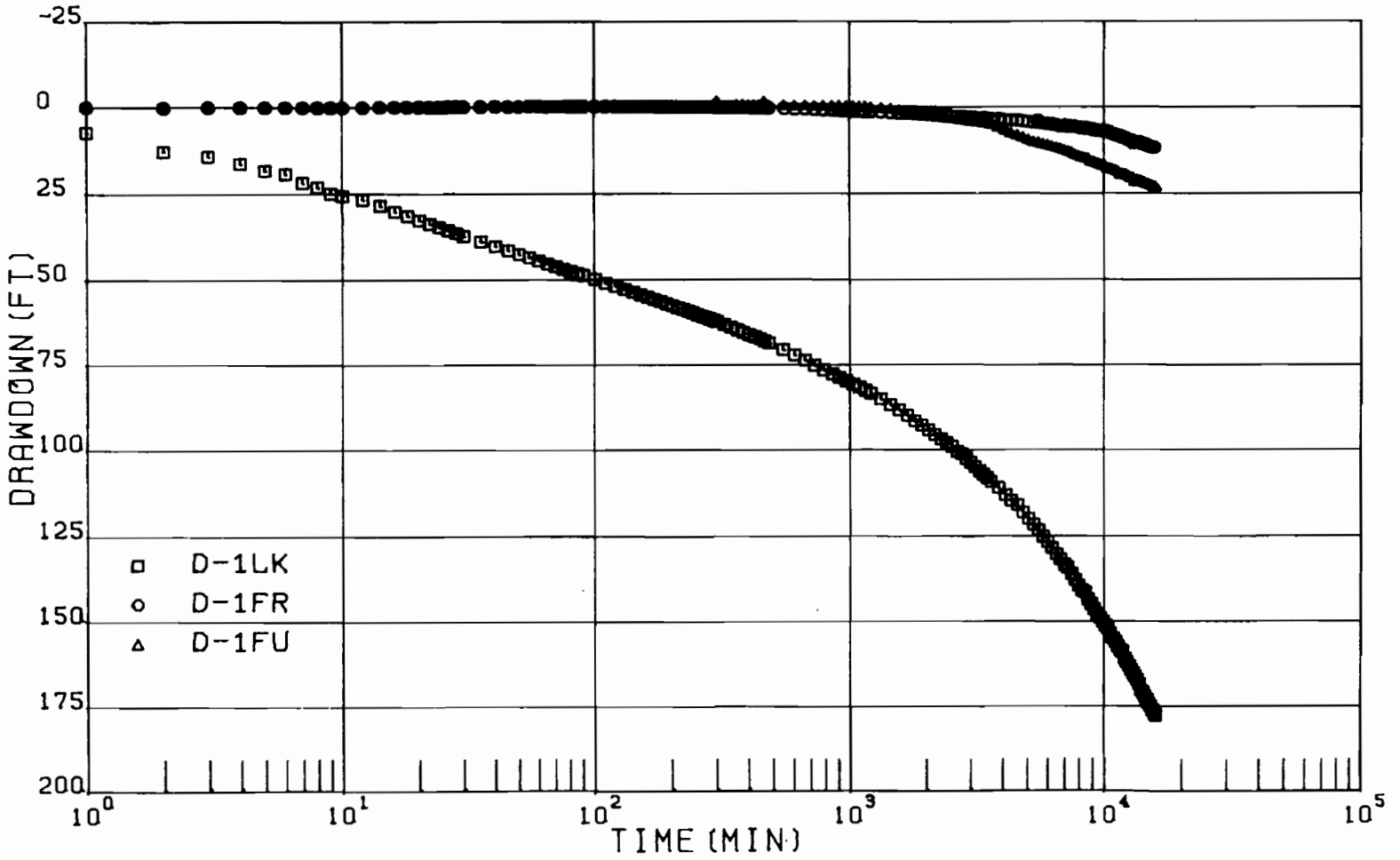


FIGURE A-3: DRAWDOWN GRAPH FOR WELL D-2LK

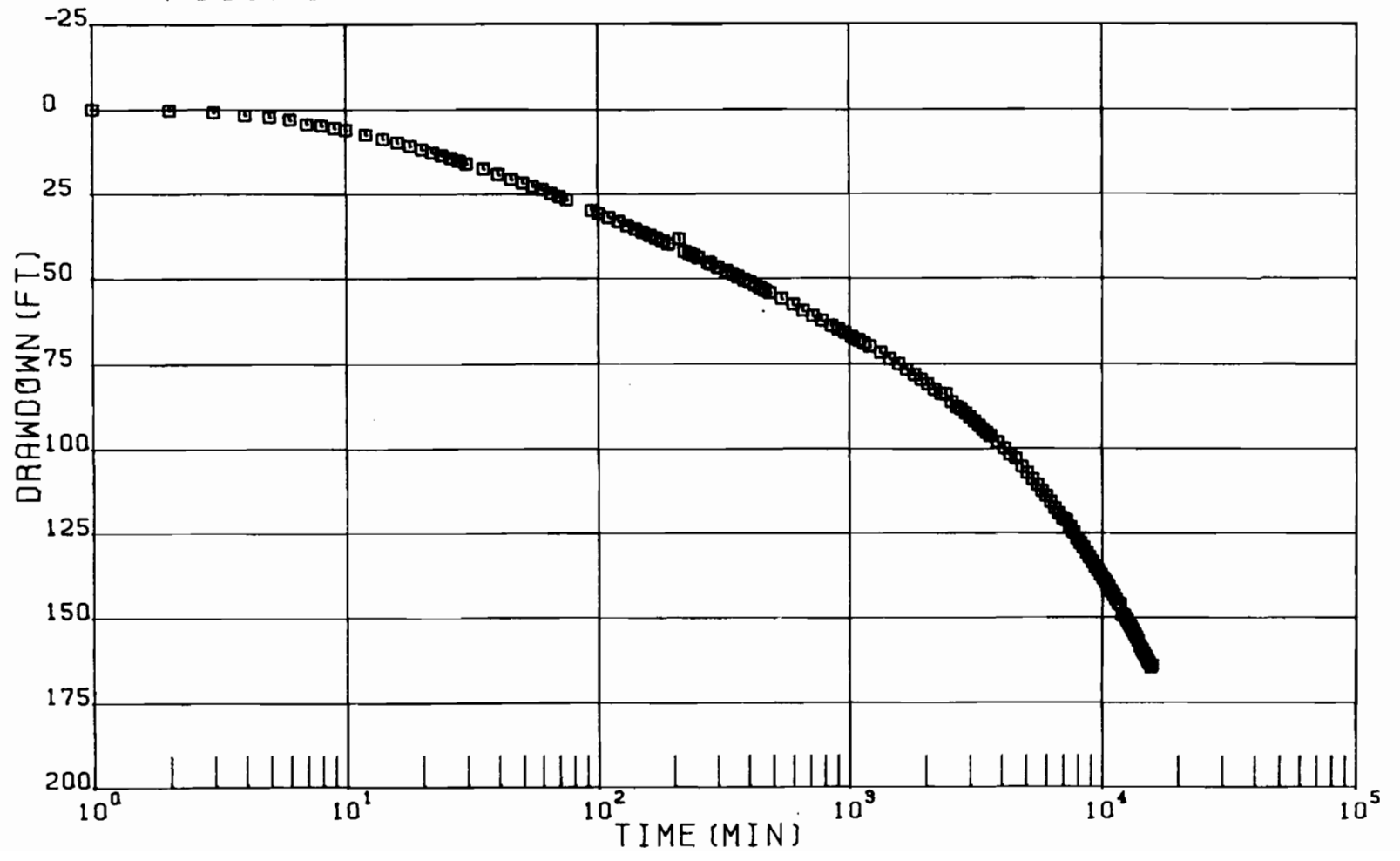


FIGURE A-4: DRAWDOWN GRAPH FOR D-3 WELL GROUP

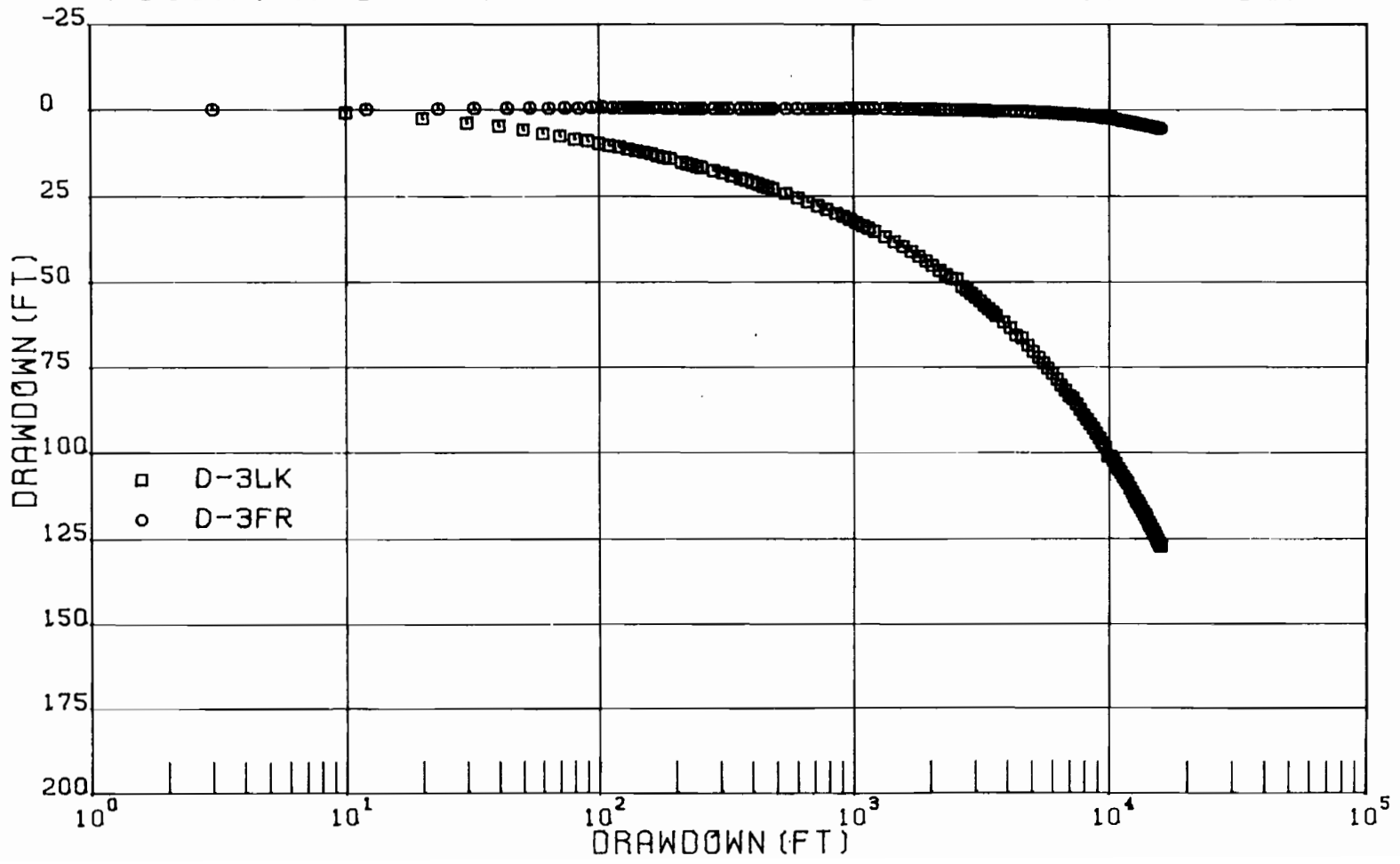


FIGURE A-5: DRAWDOWN GRAPH FOR D-4 WELL GROUP

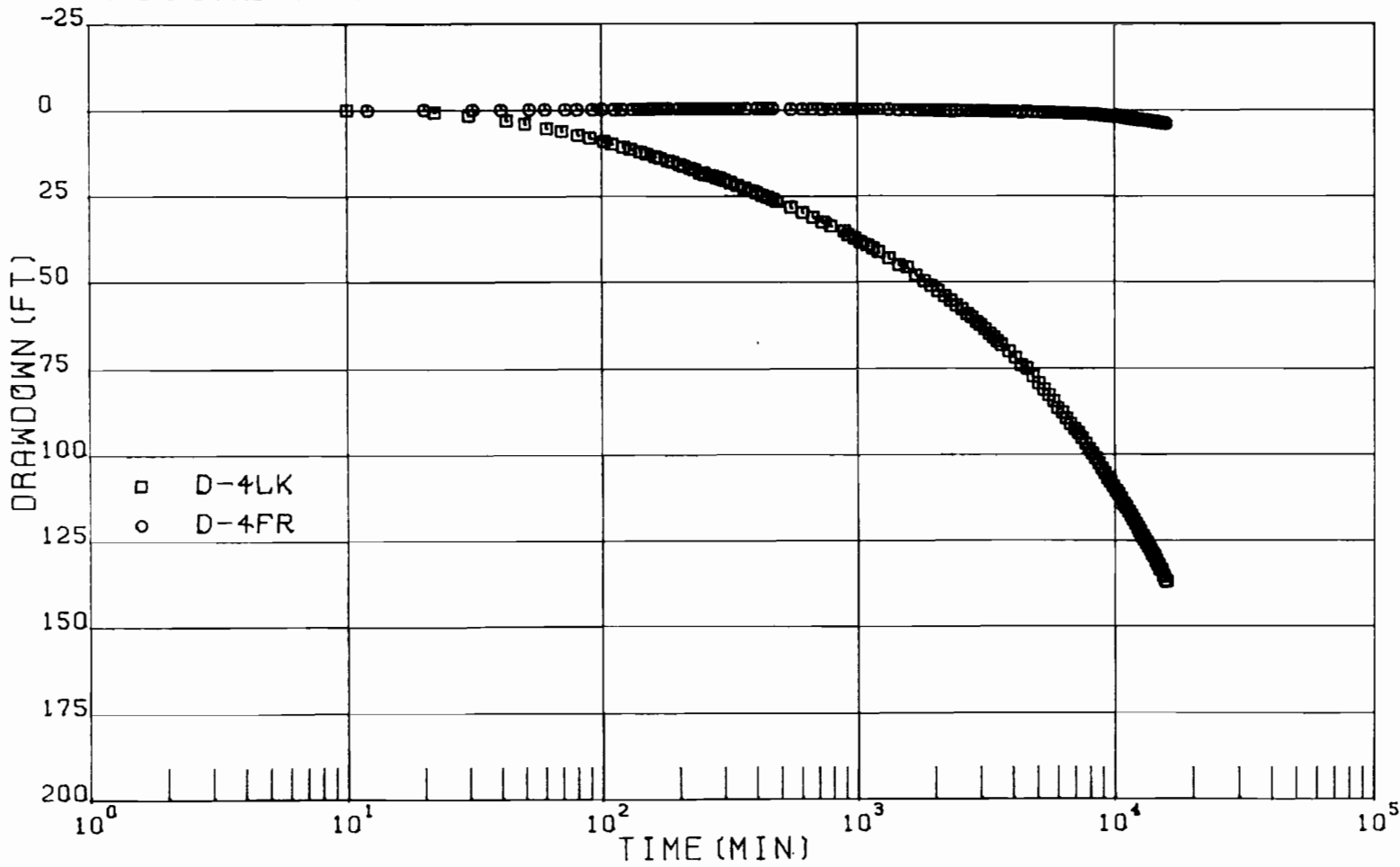


FIGURE A-6: DRAWDOWN GRAPH FOR WELL D-5LK

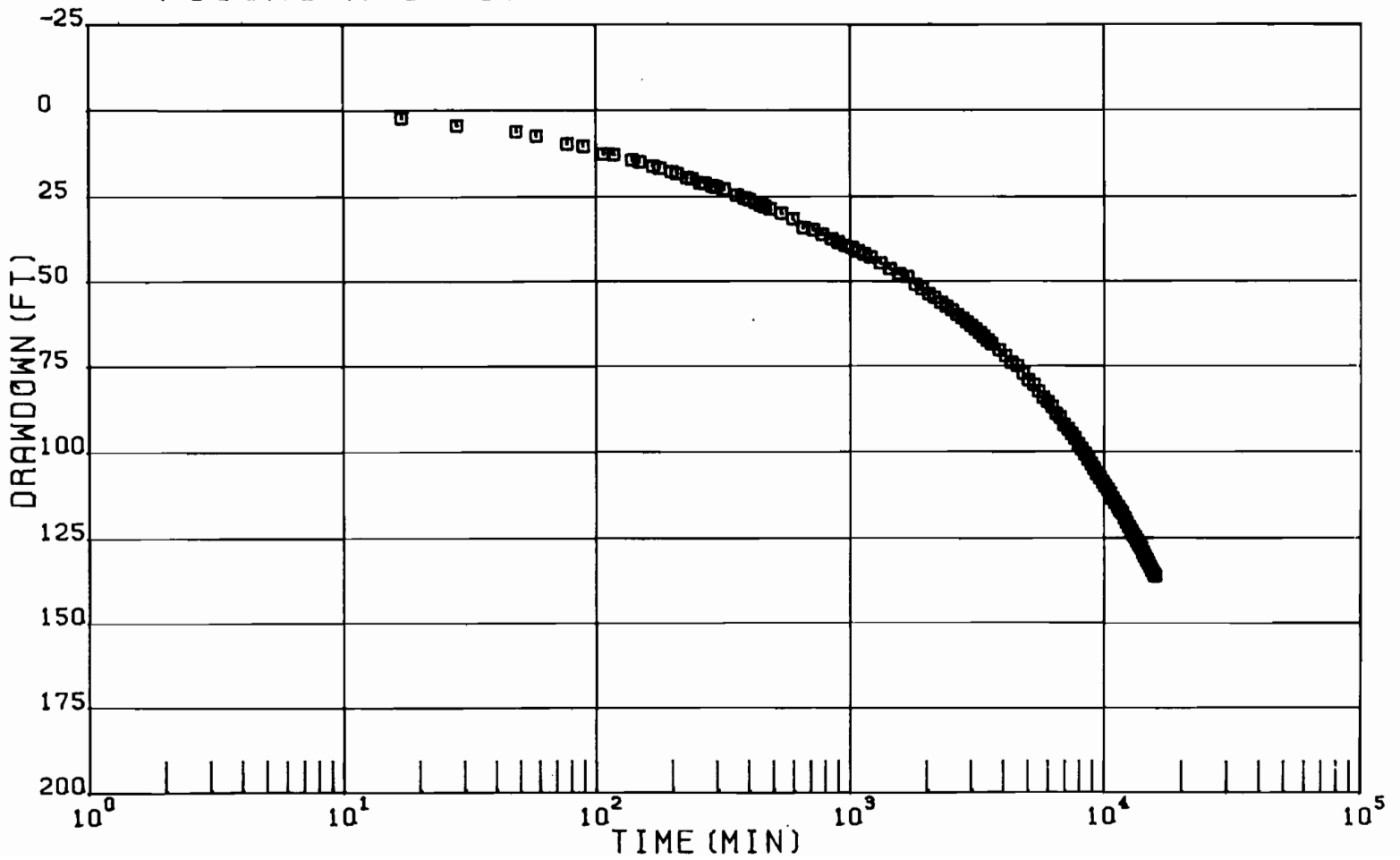


FIGURE A-7: DRAWDOWN GRAPH FOR WELL D-6LK

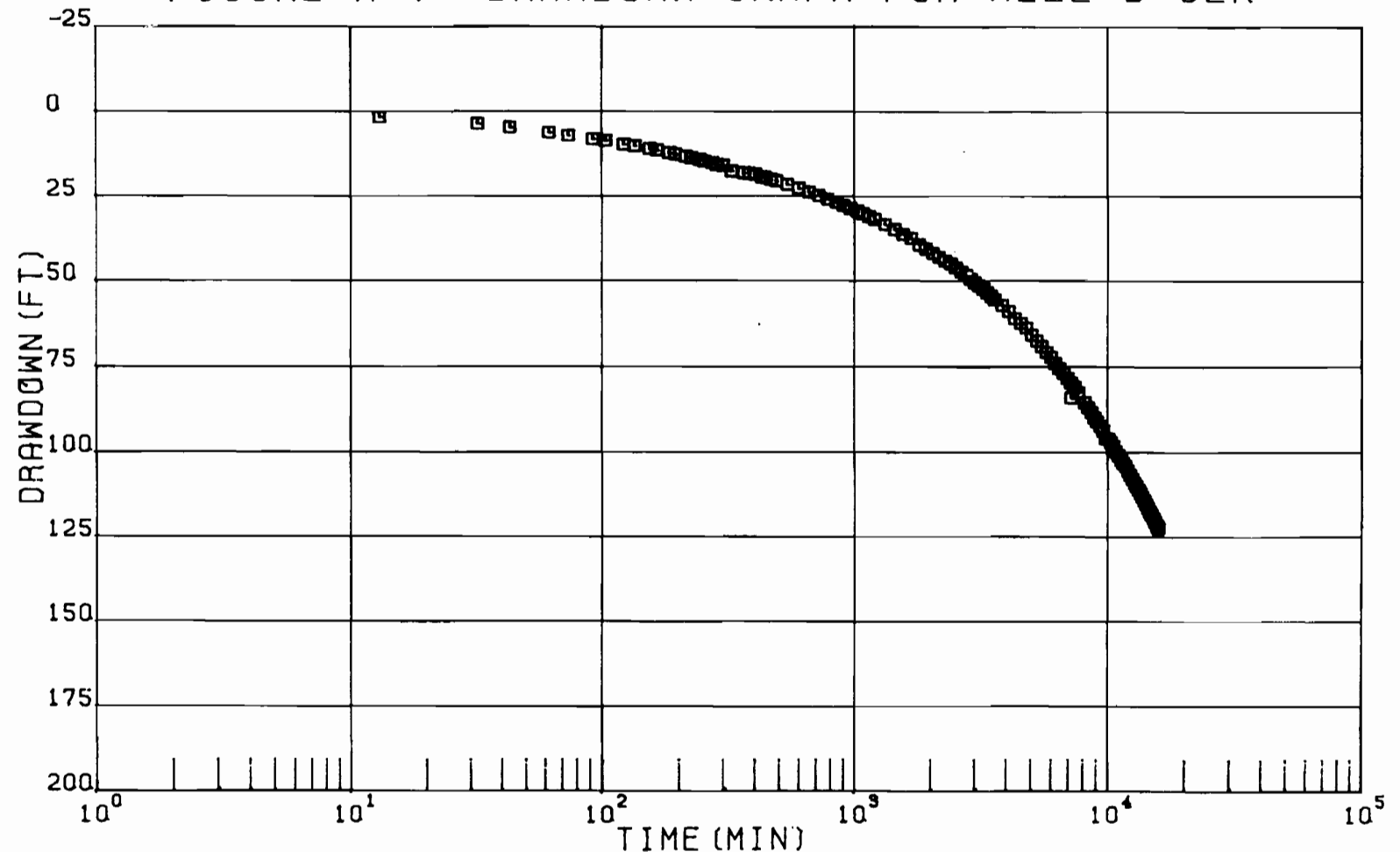


FIGURE A-8: DRAWDOWN GRAPH FOR WELL D-8LK

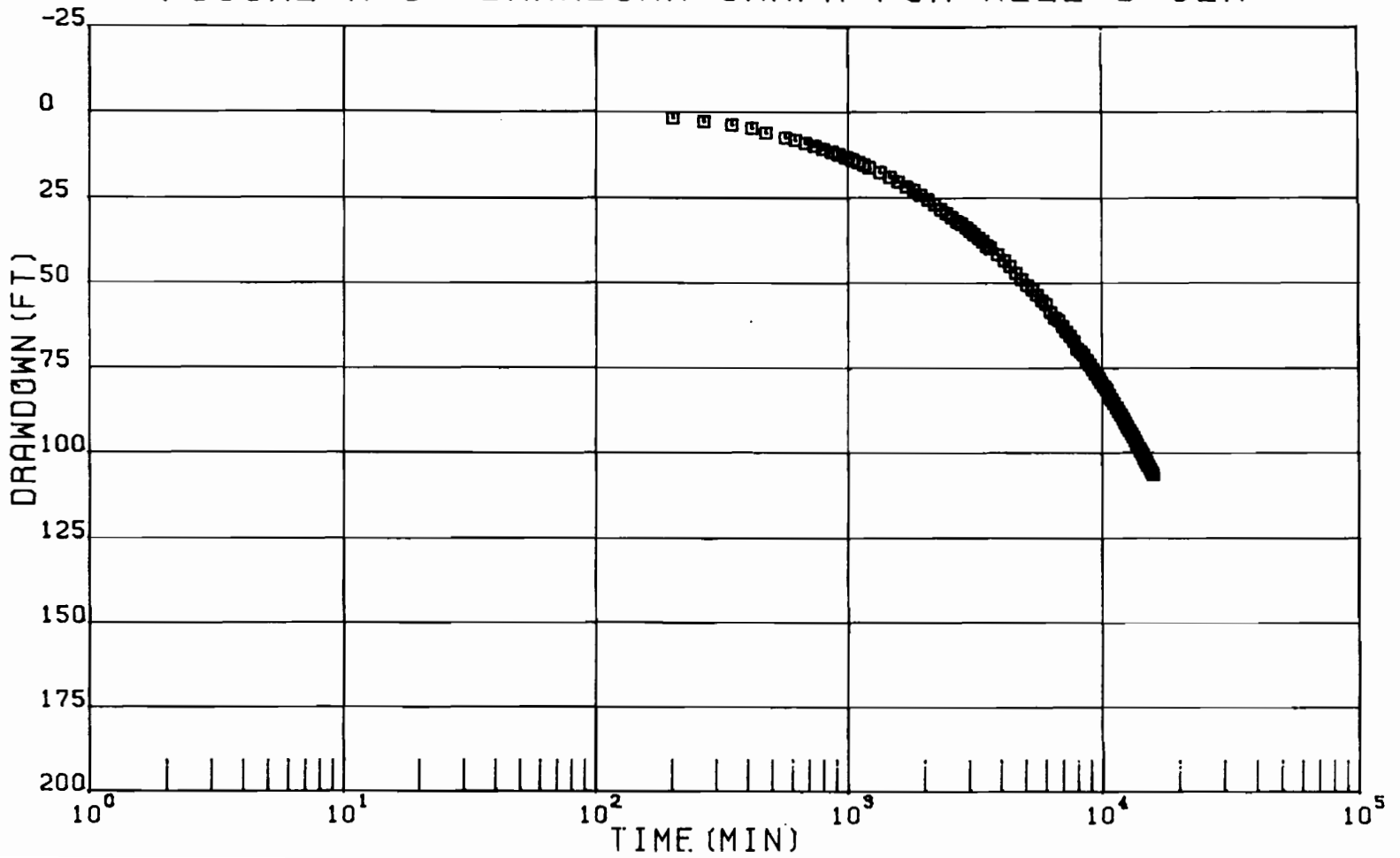
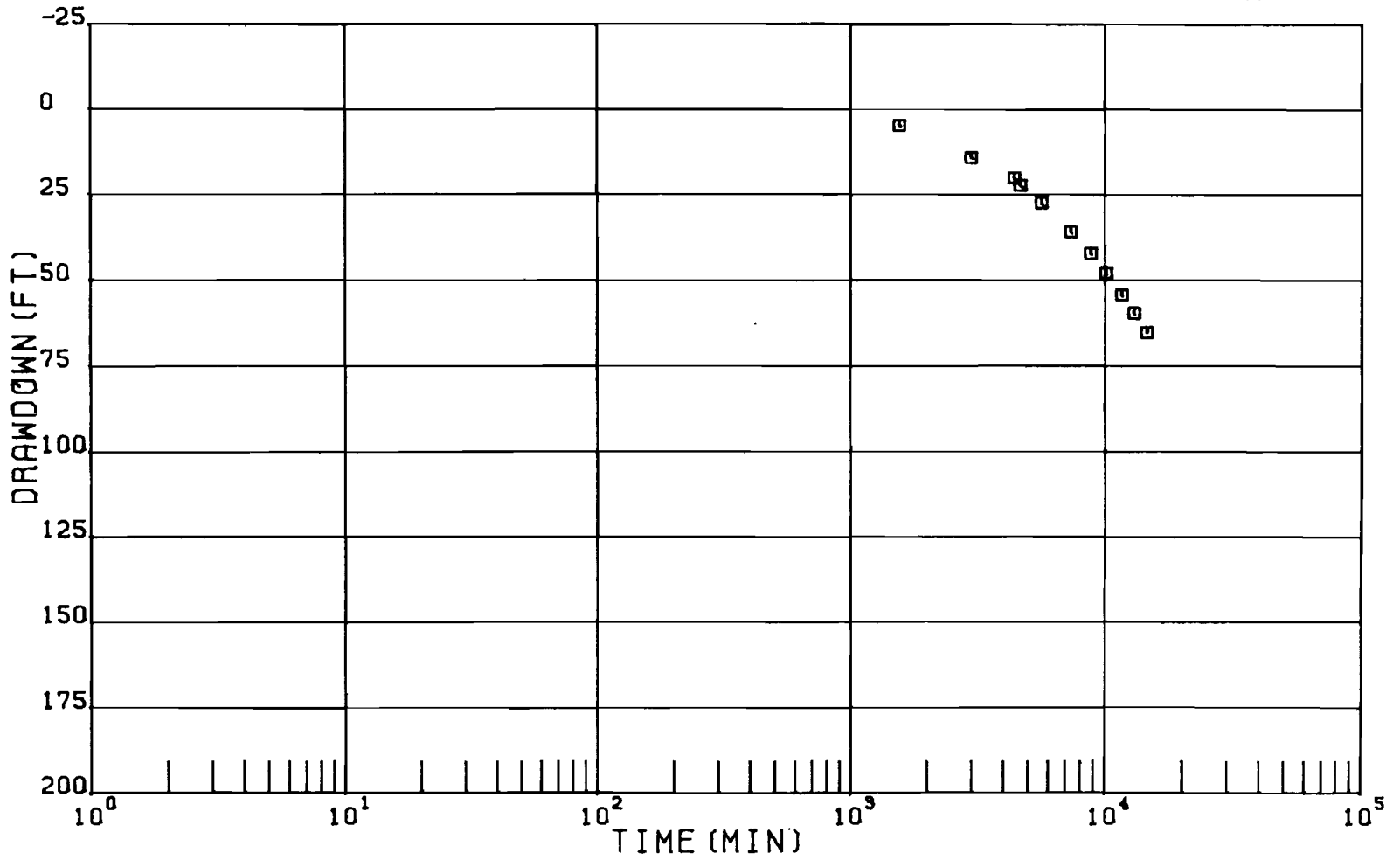




FIGURE A-9: DRAWDOWN GRAPH FOR WELL D-20LK



APPENDIX B

LOGARITHMIC TIME-DRAWDOWN GRAPHS

FIGURE B-1: DRAWDOWN GRAPH FOR WELL D-PW

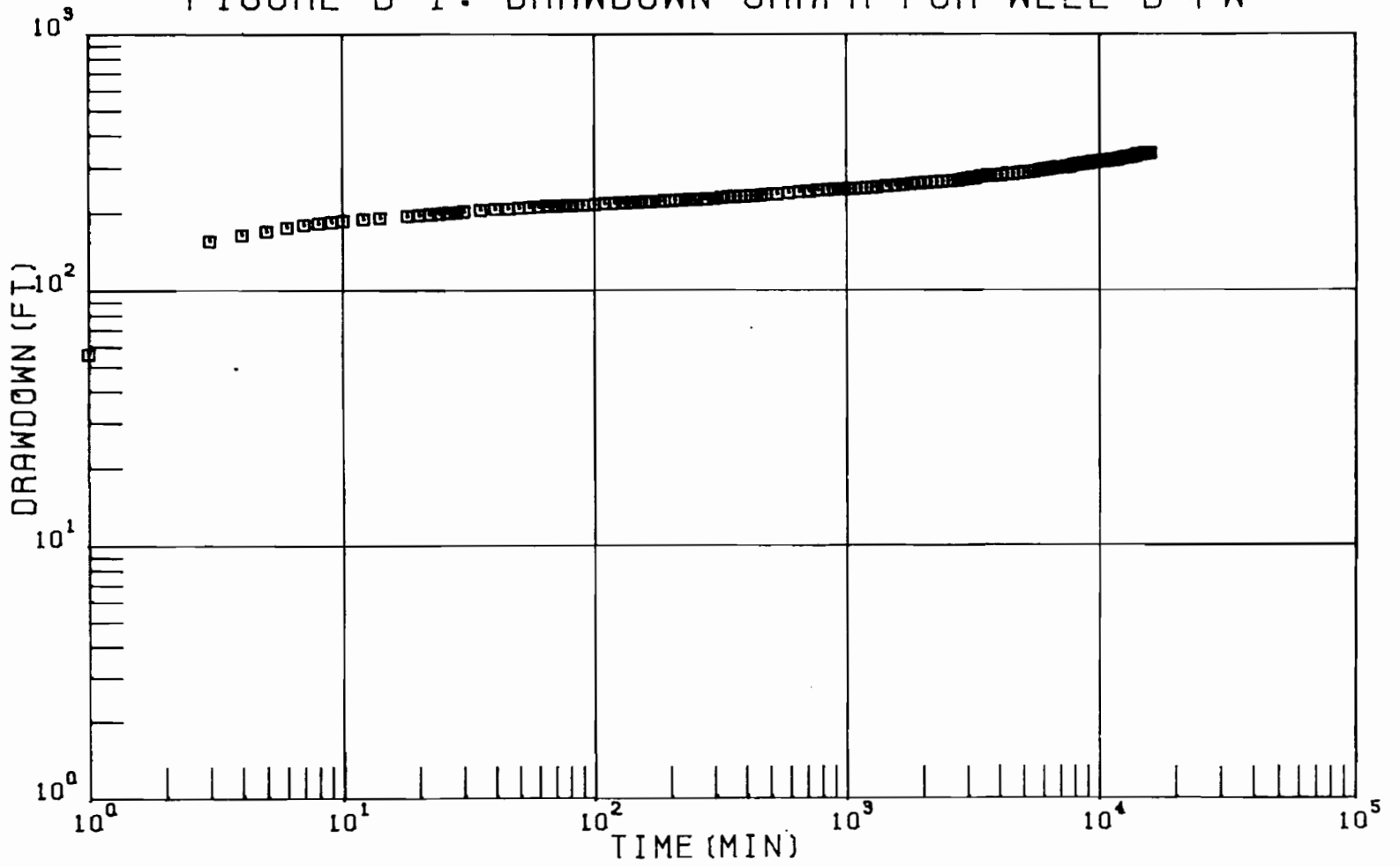


FIGURE B-2: DRAWDOWN GRAPH FOR D-1 WELL GROUP

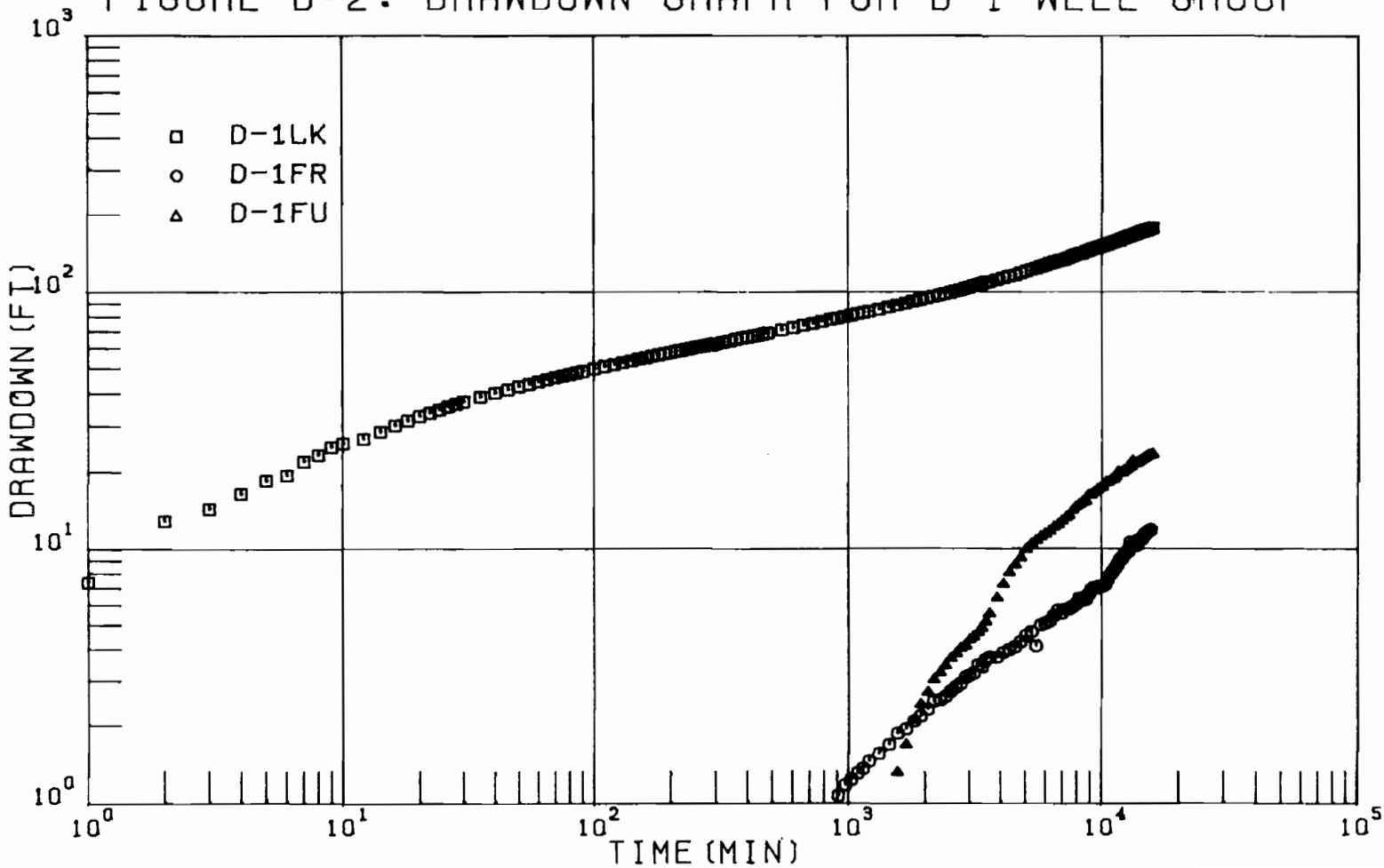
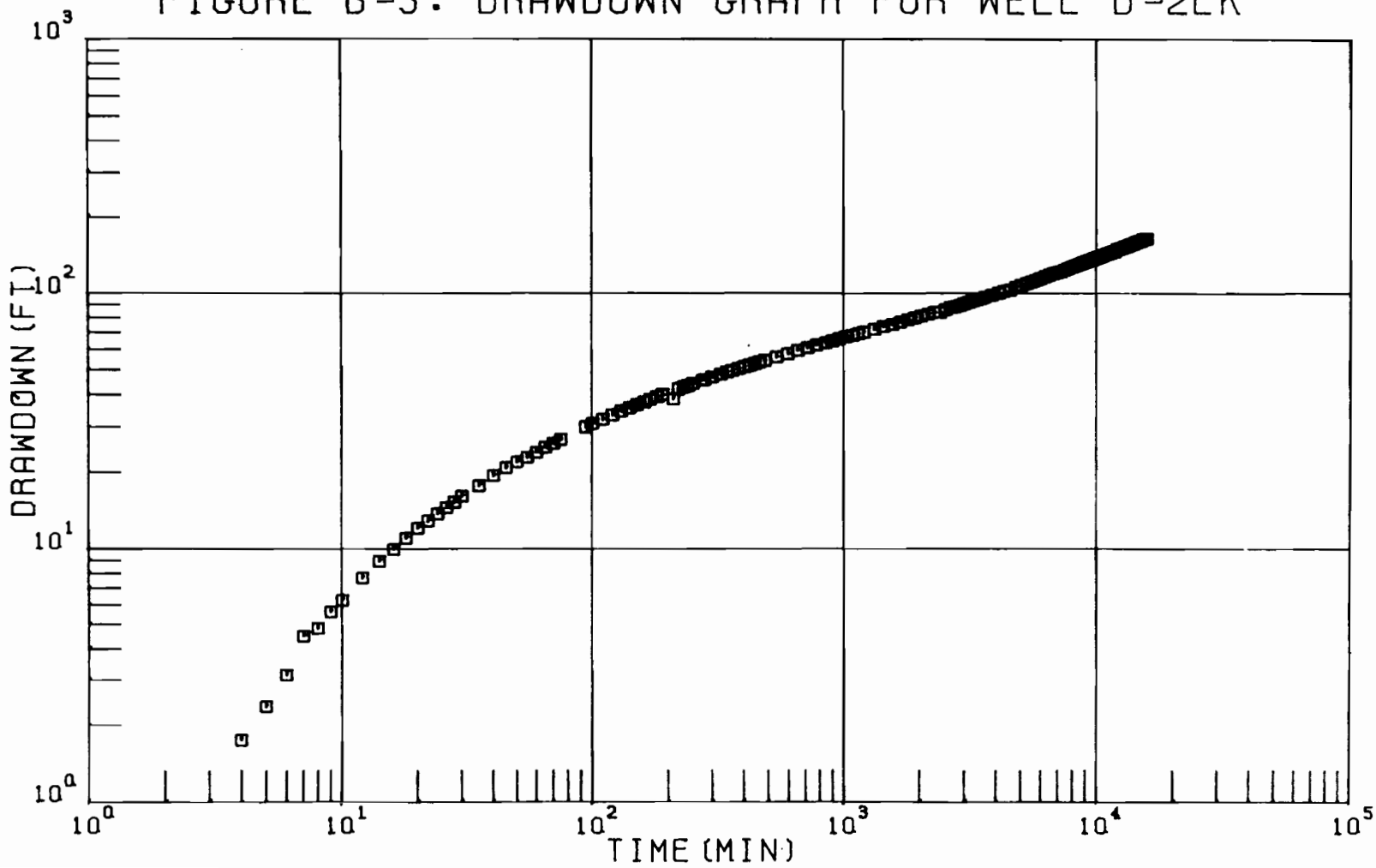


FIGURE B-3: DRAWDOWN GRAPH FOR WELL D-2LK



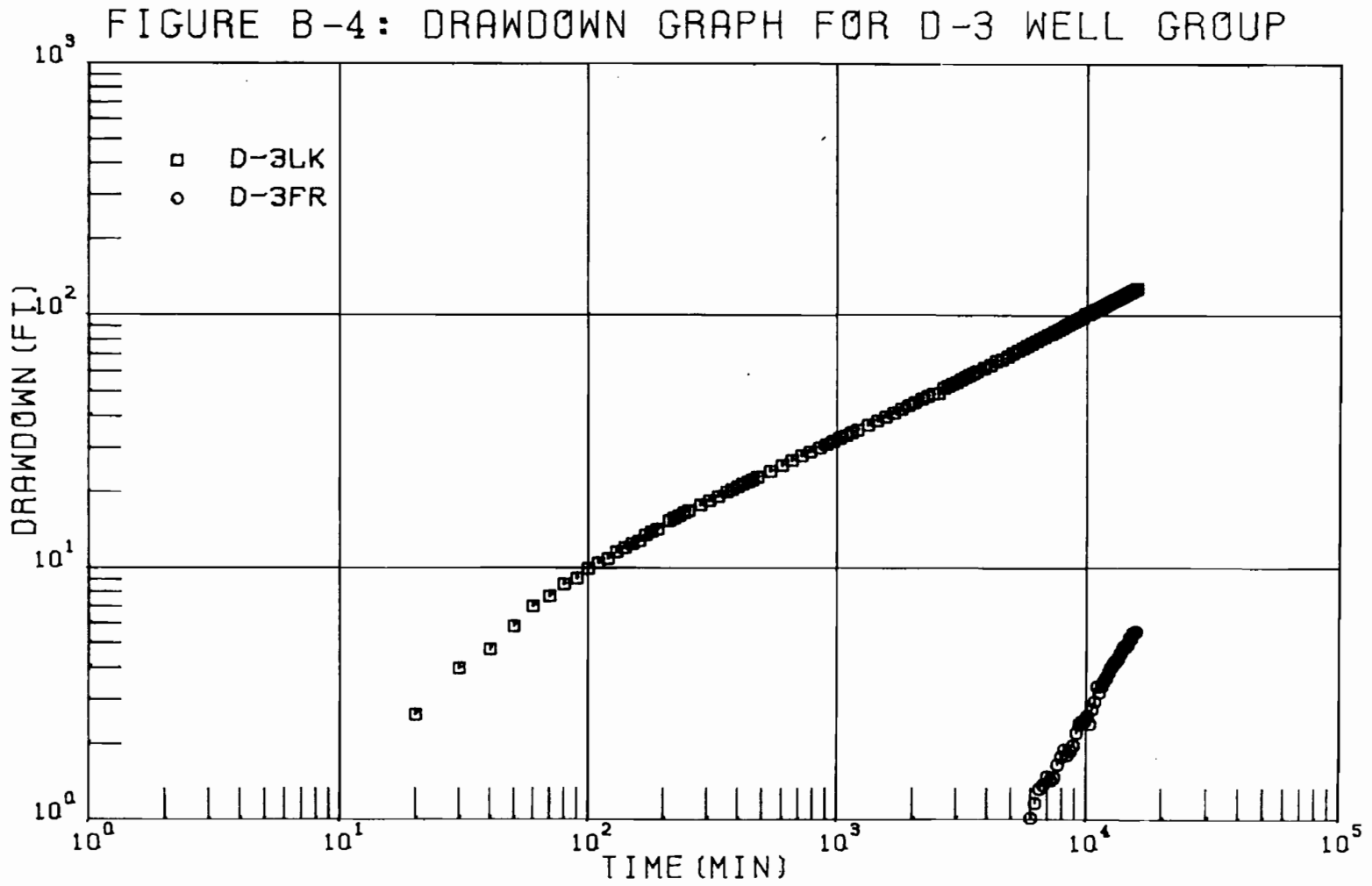


FIGURE B-5: DRAWDOWN GRAPH FOR D-4 WELL GROUP

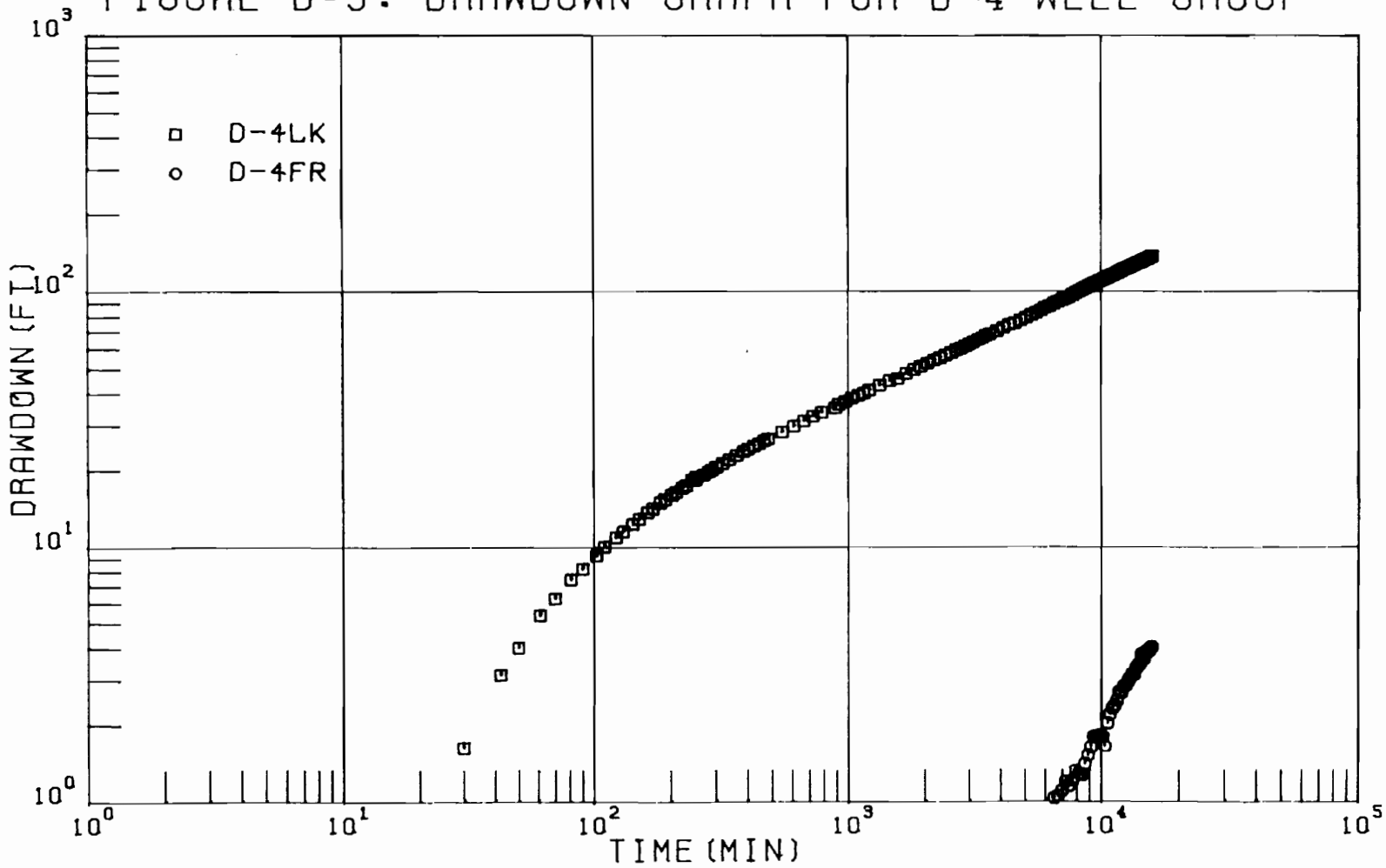


FIGURE B-6: DRAWDOWN GRAPH FOR WELL D-5LK

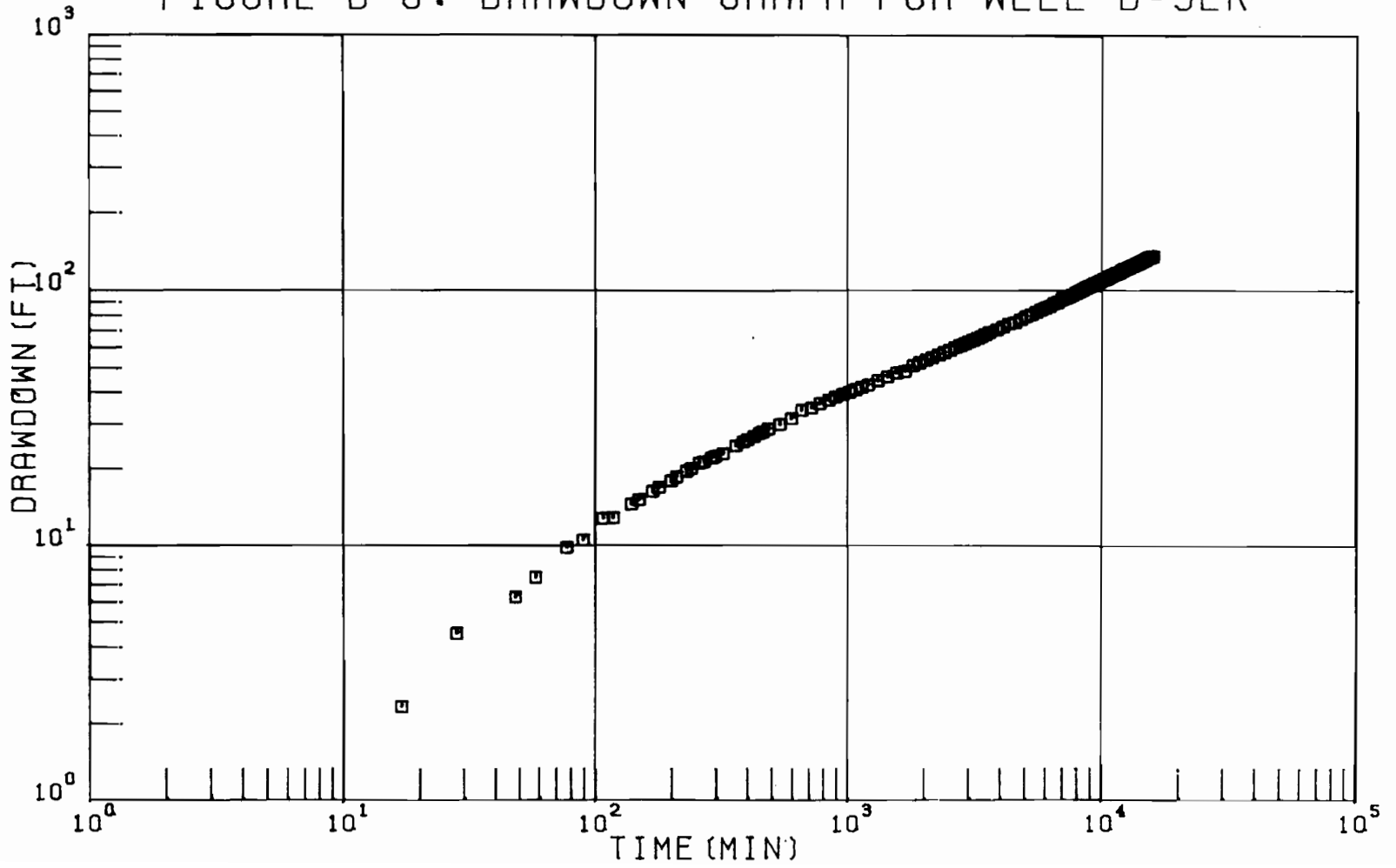




FIGURE B-7: DRAWDOWN GRAPH FOR WELL D-6LK

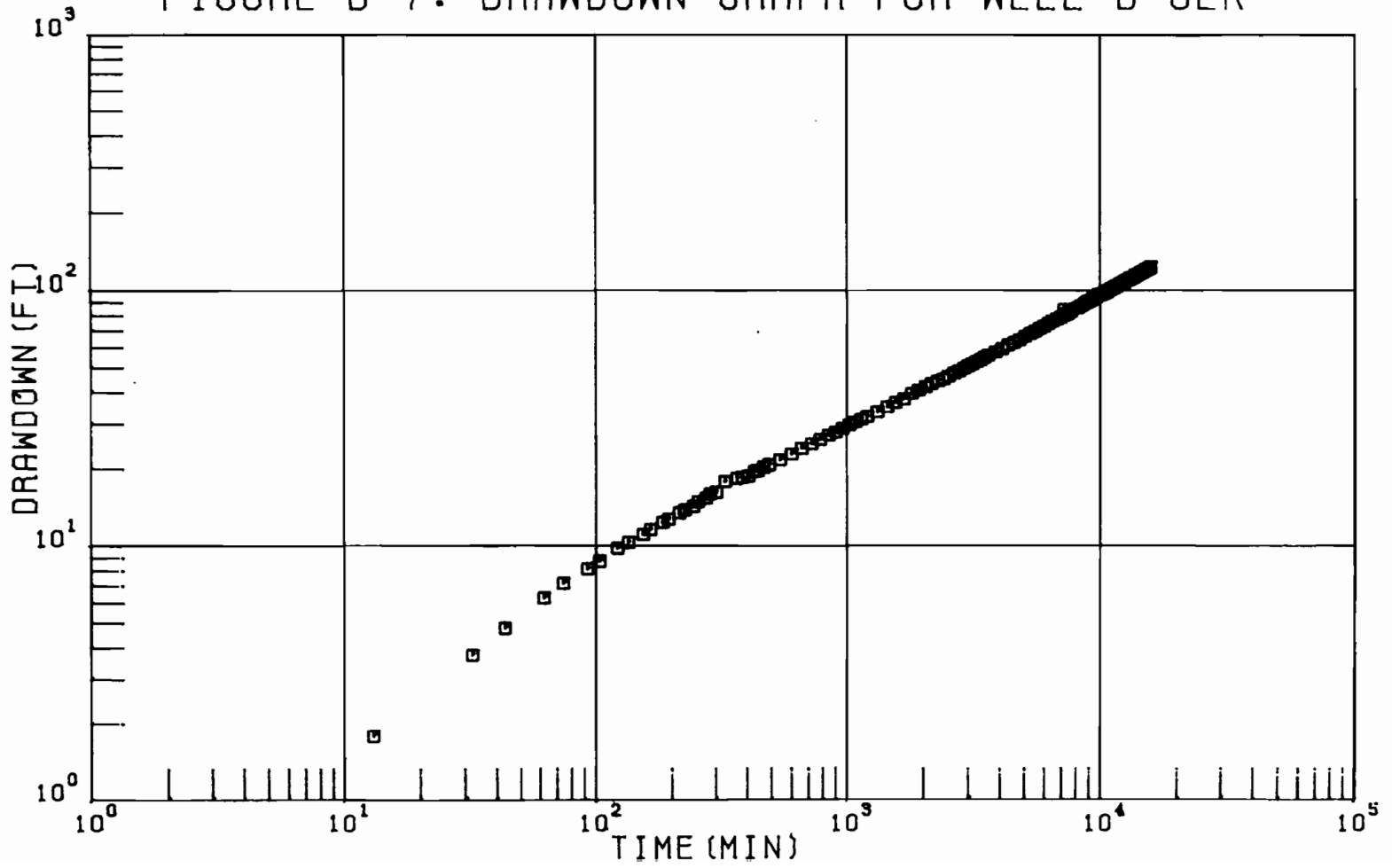


FIGURE B-8: DRAWDOWN GRAPH FOR WELL D-8LK

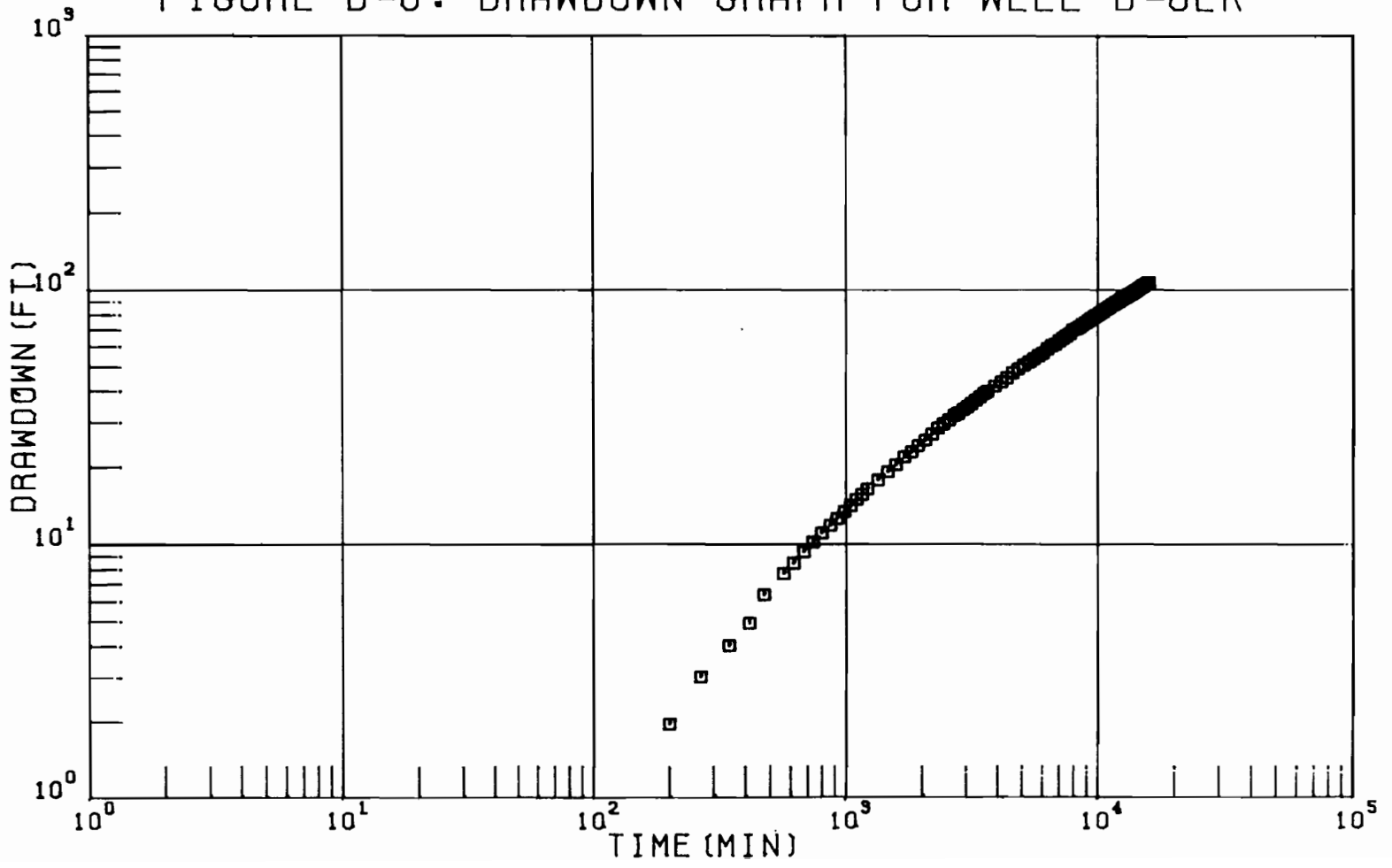
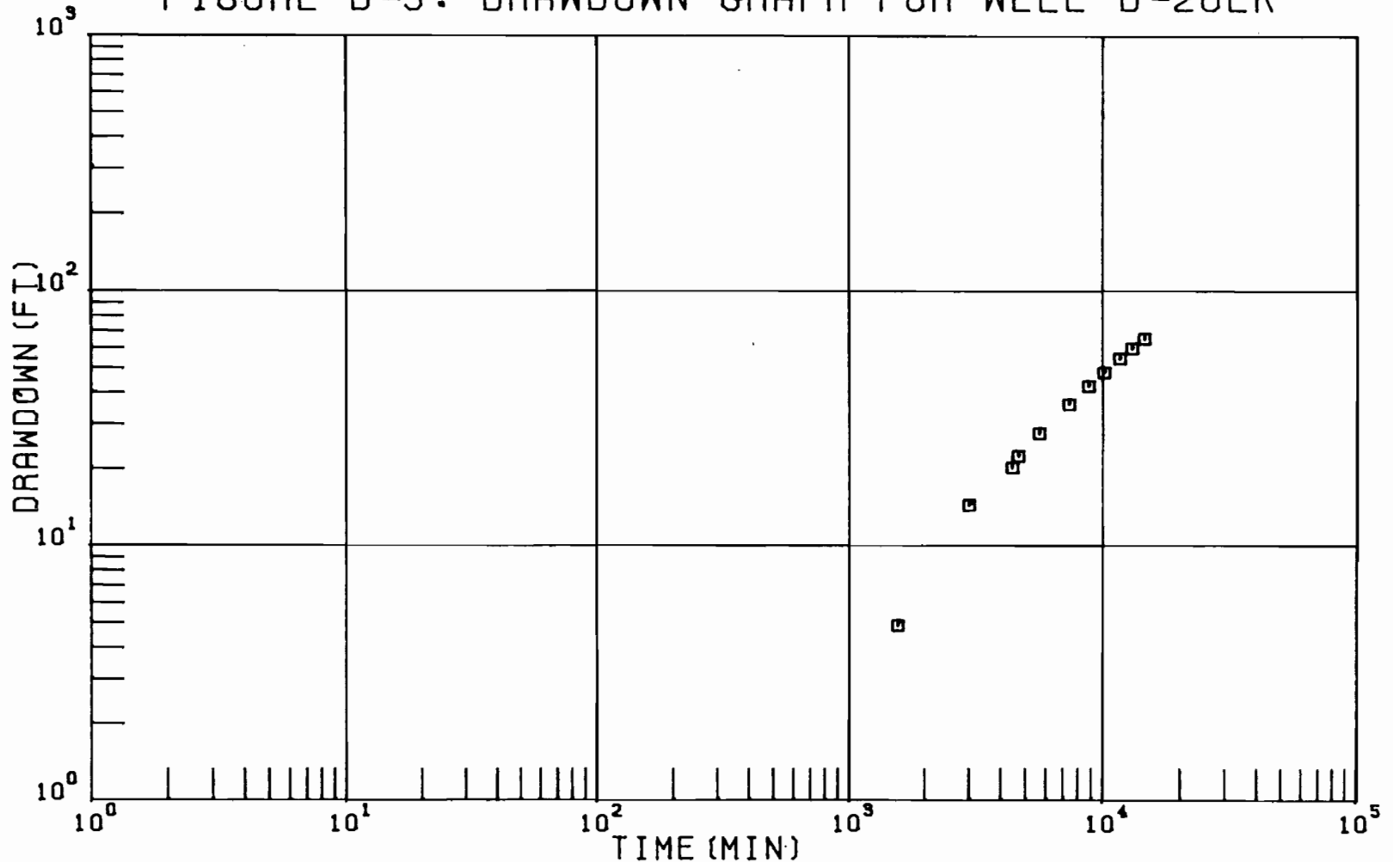


FIGURE B-9: DRAWDOWN GRAPH FOR WELL D-20LK



APPENDIX C

SEMILOGARITHMIC TIME-RESIDUAL DRAWDOWN GRAPHS

FIGURE C-1: RECOVERY GRAPH FOR WELL D-PW

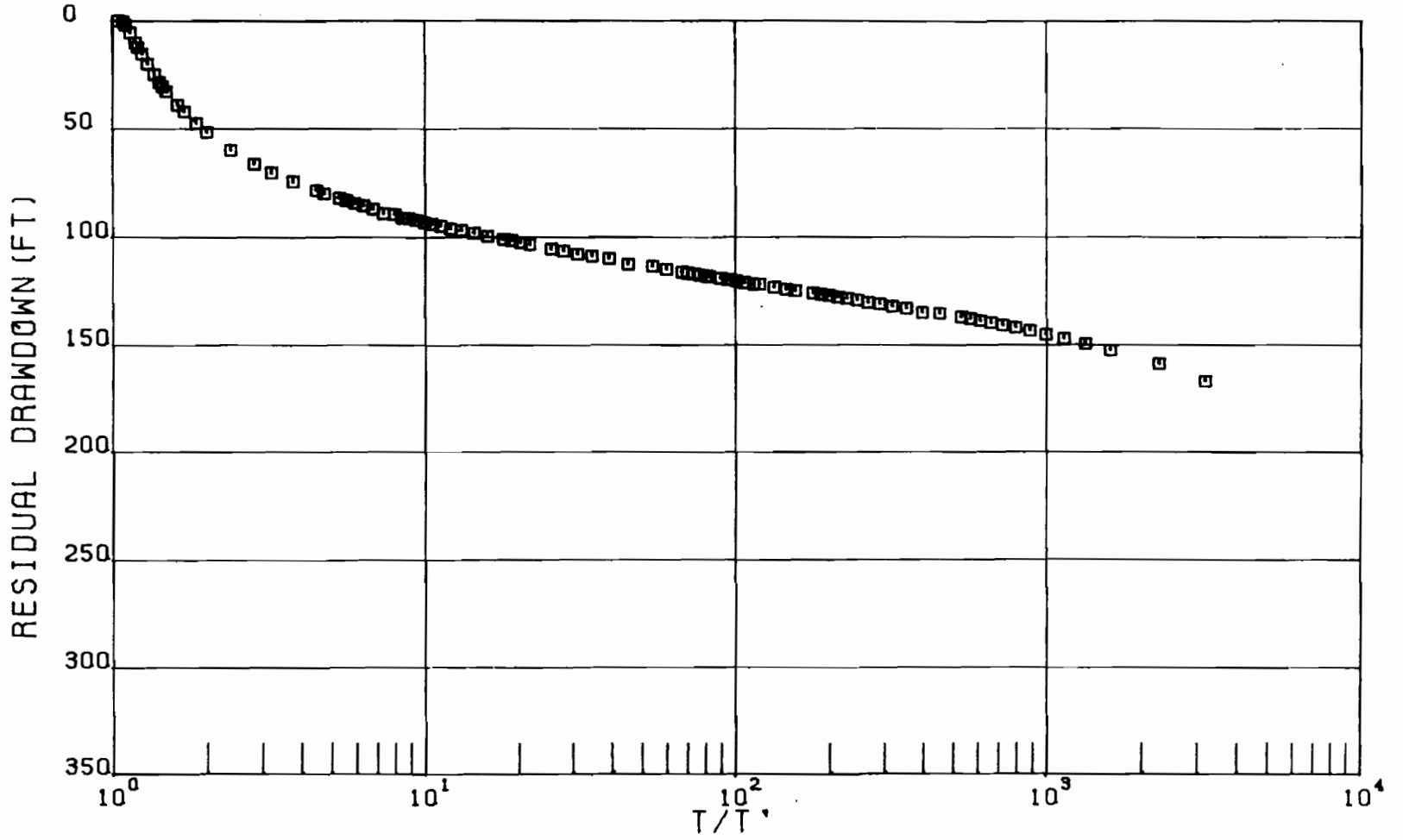


FIGURE C-2: RECOVERY GRAPH FOR D-1 WELL GROUP

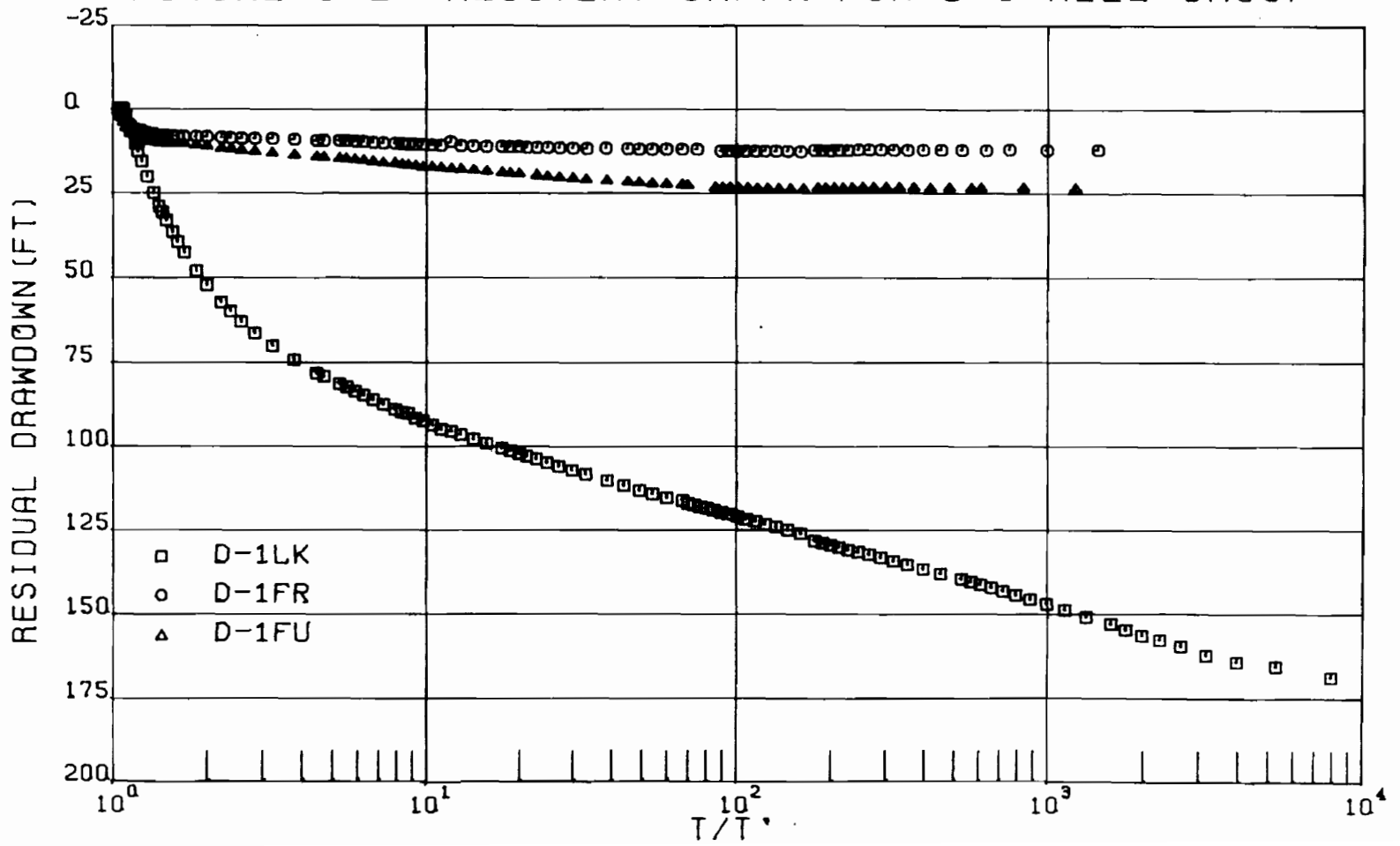


FIGURE C-3: RECOVERY GRAPH FOR WELL D-2LK

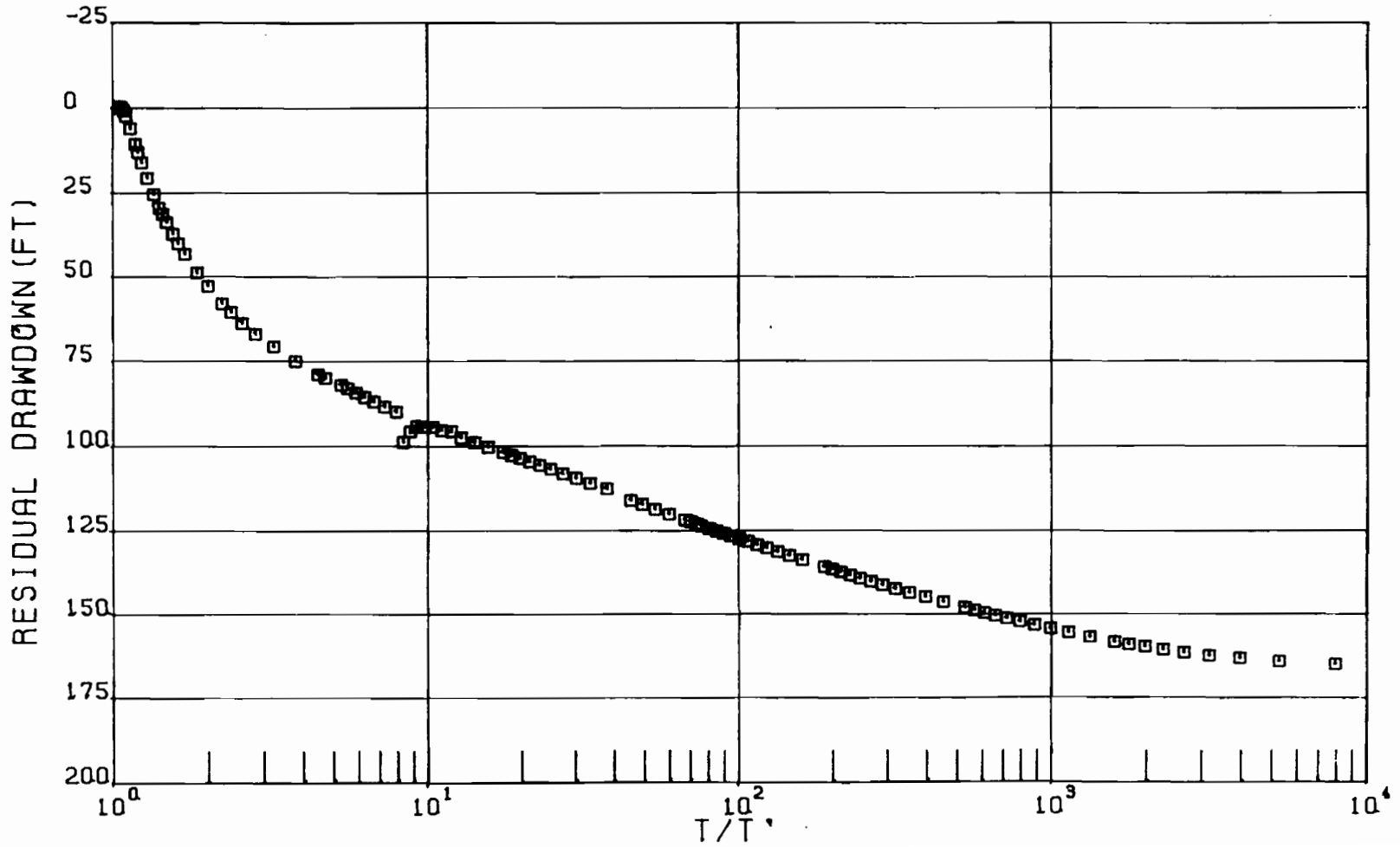


FIGURE C-4: RECOVERY GRAPH FOR D-3 WELL GROUP

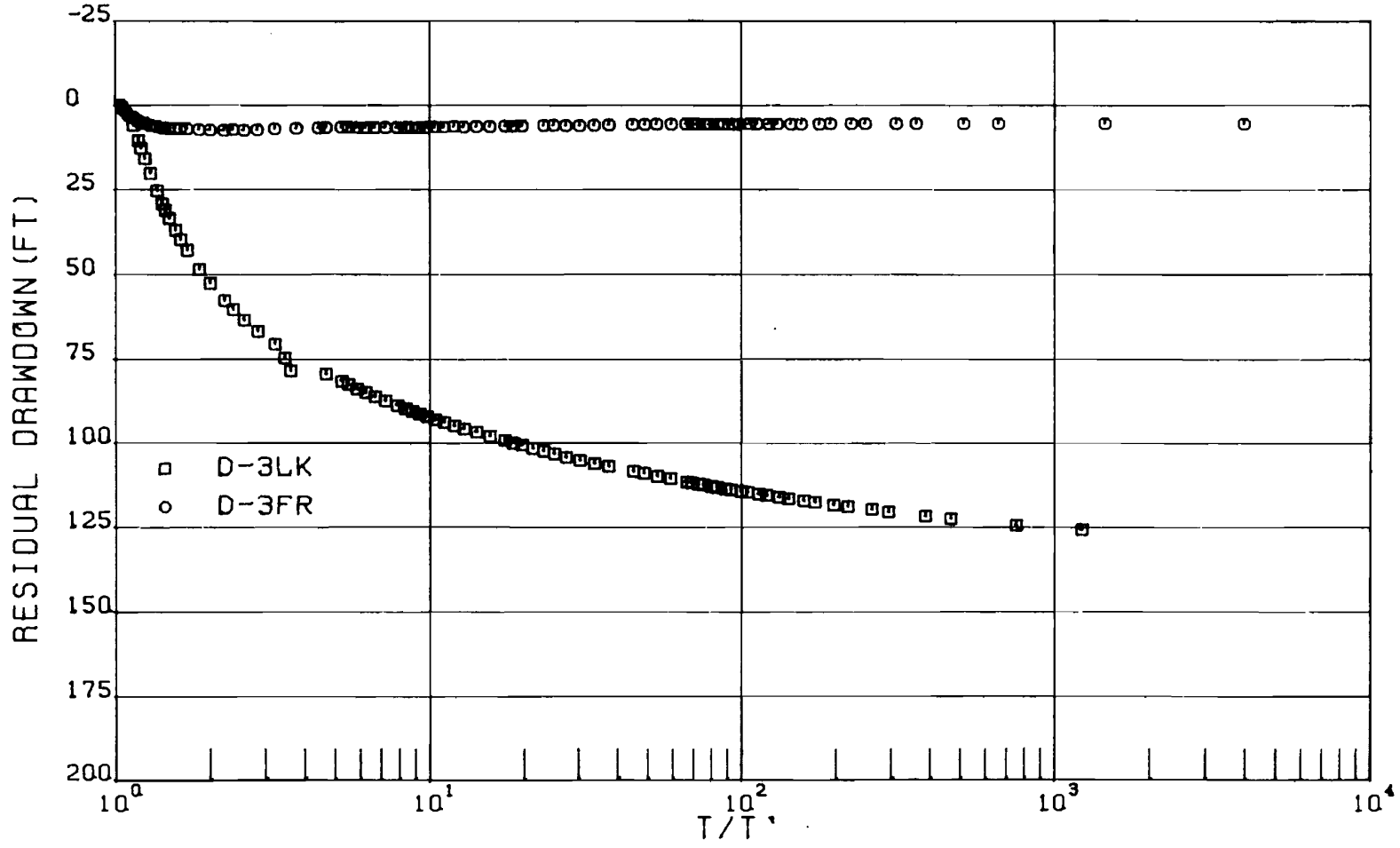




FIGURE C-5: RECOVERY GRAPH FOR D-4 WELL GROUP

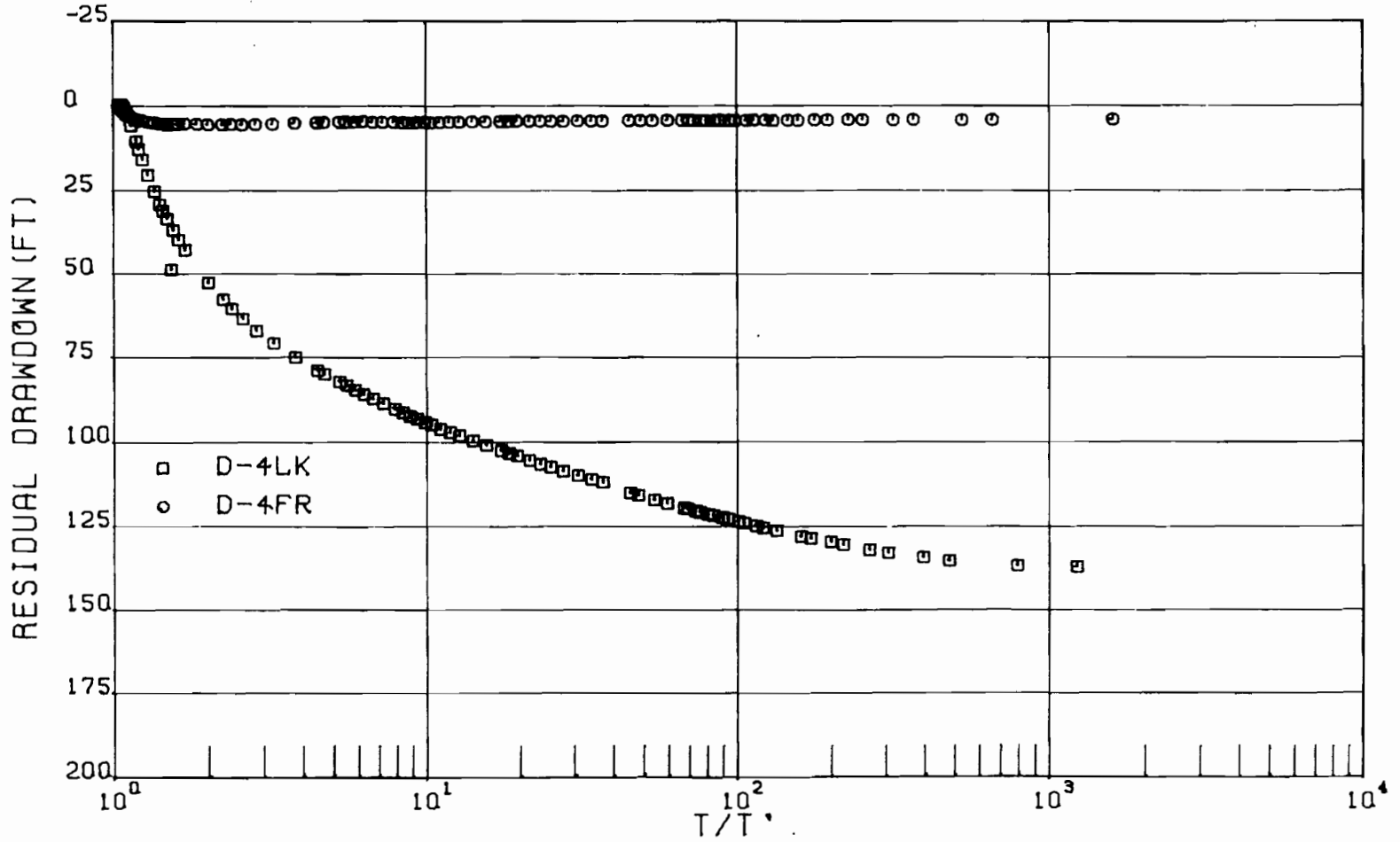


FIGURE C-6: RECOVERY GRAPH FOR WELL D-5LK

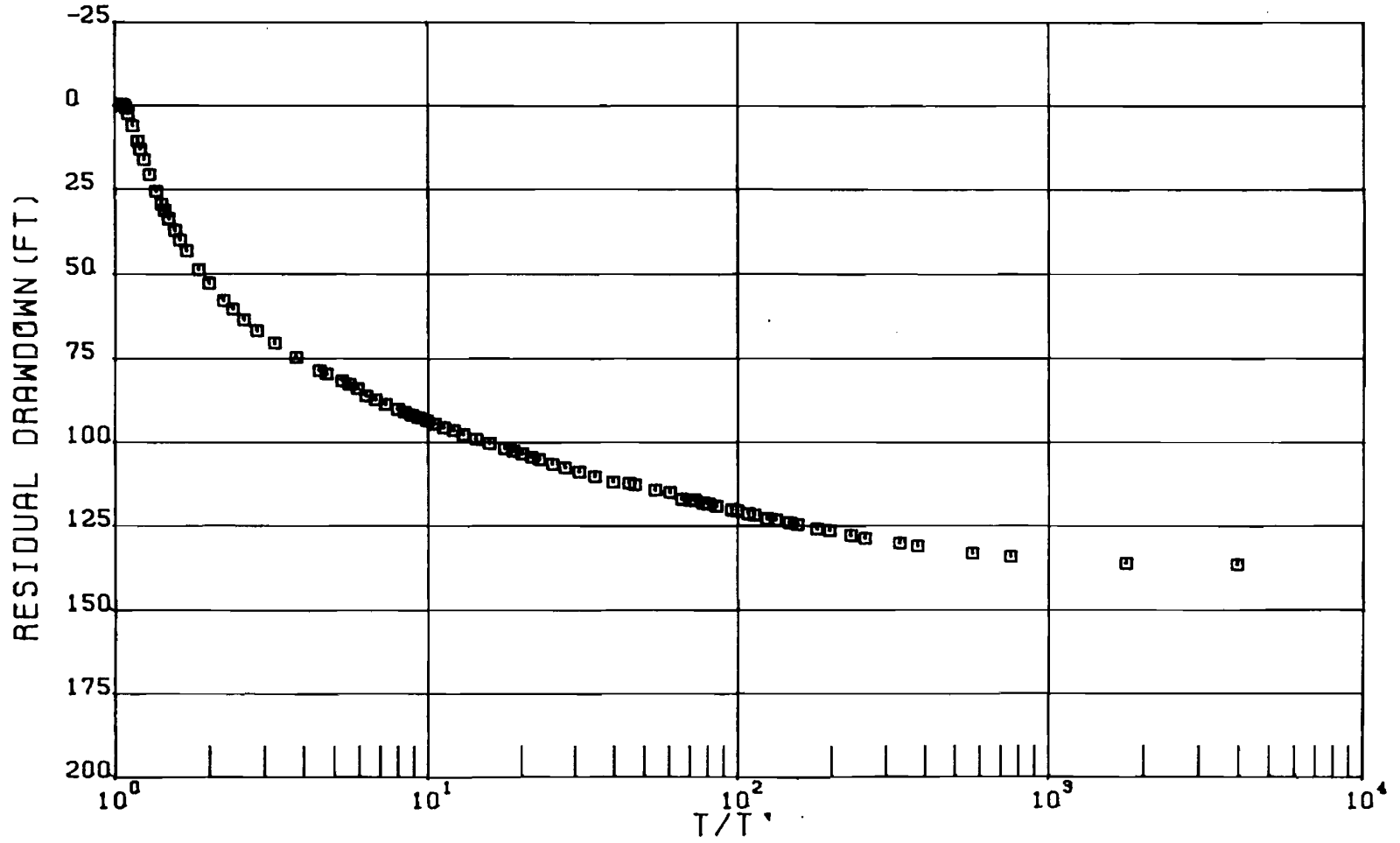


FIGURE C-7: RECOVERY GRAPH FOR WELL D-6LK

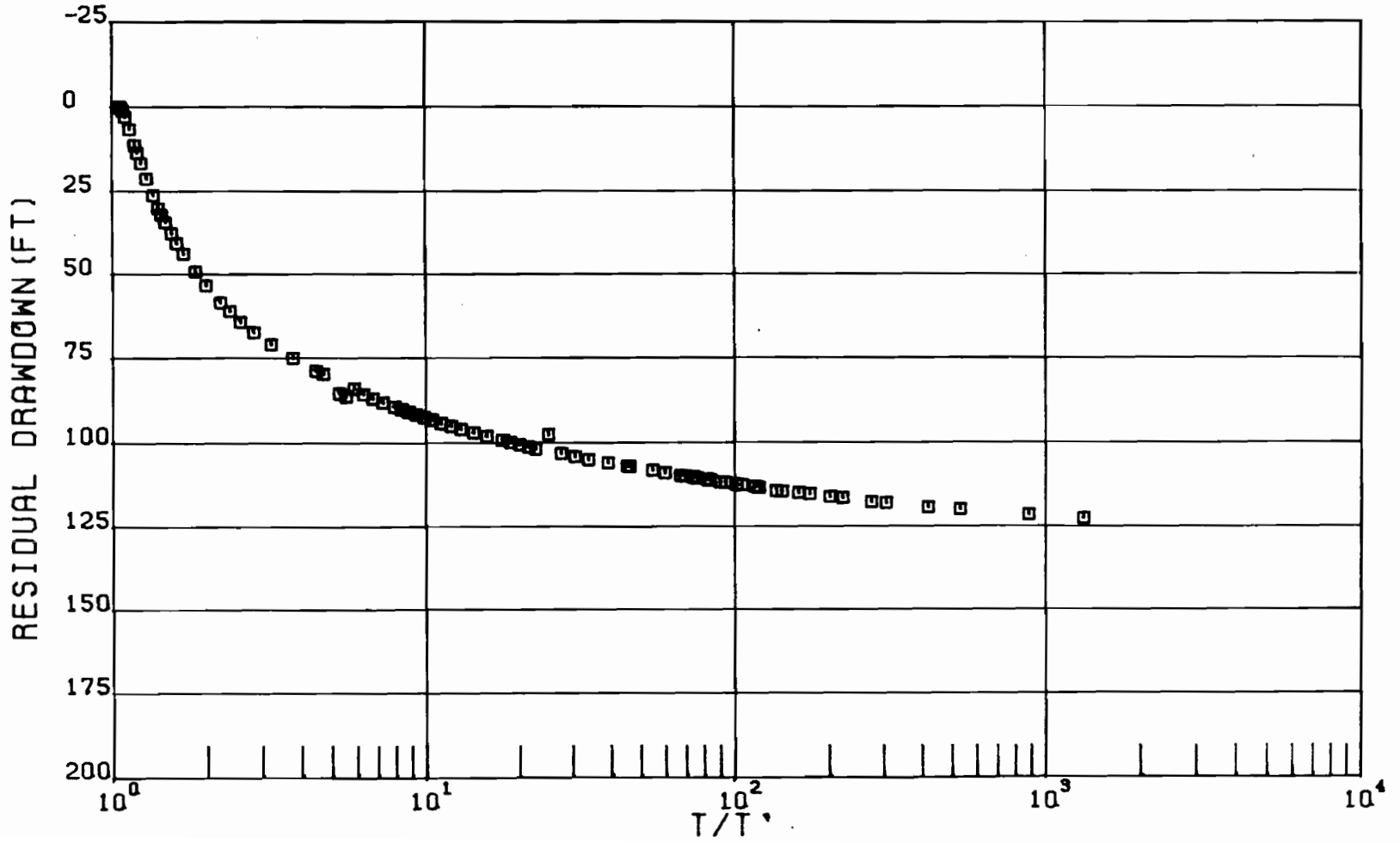
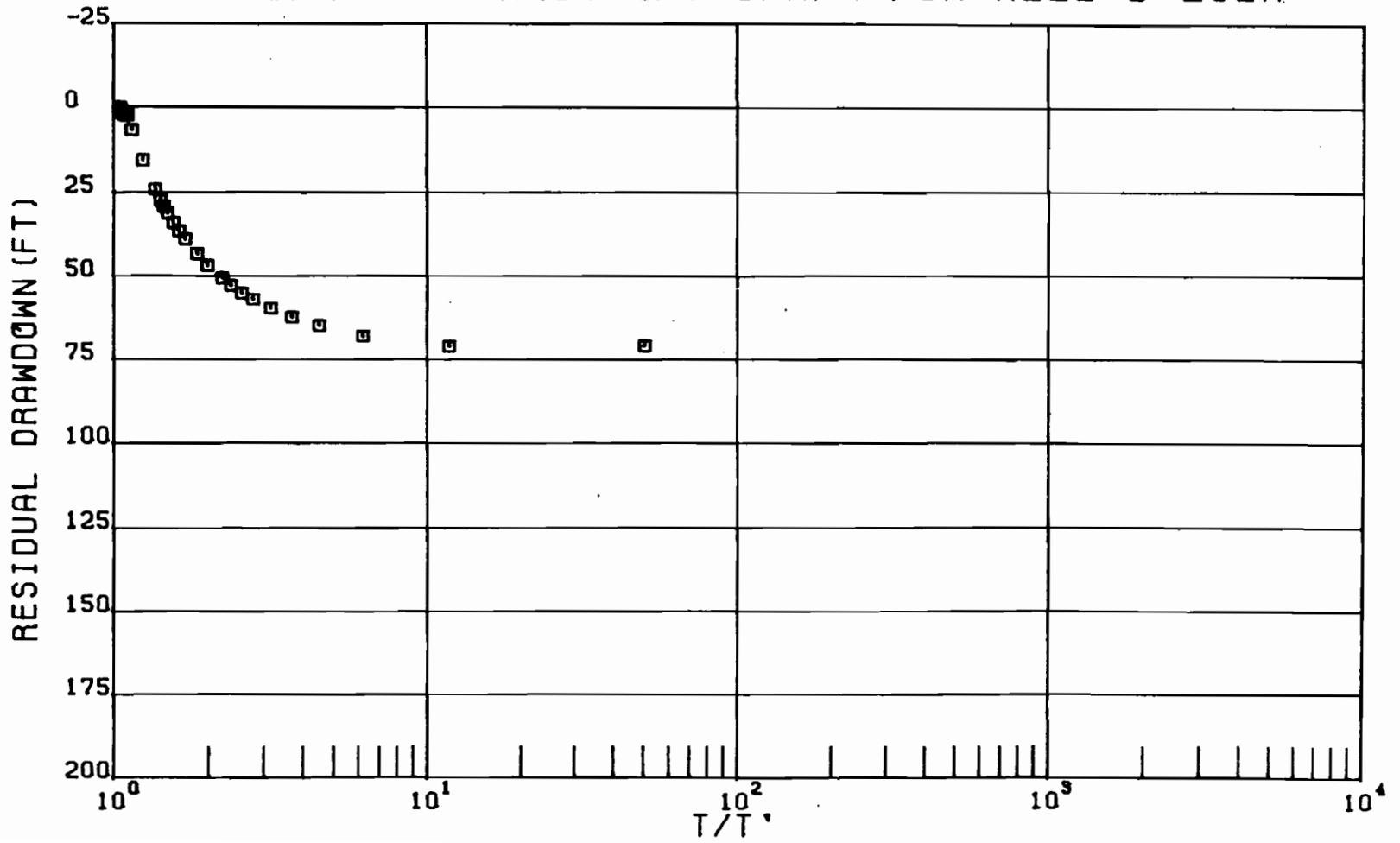


FIGURE C-9: RECOVERY GRAPH FOR WELL D-20LK



**APPENDIX 2.7-L**

**Class V UIC Application**

# **UIC PERMIT APPLICATION**

## **Class V Non-Hazardous Injection Wells**

**Powertech (USA) Inc.**

**Dewey-Burdock Project**

**Custer and Fall River Counties, South Dakota**

**EPA Permit # TBD**

**March 2010**

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|--------------|---|
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**APPENDICES**

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APPENDIX C ELECTRONIC COPY OF PERMIT APPLICATION

APPENDIX D HISTORICAL PHOTO, CITY OF EDGEMONT WATER WELL

**USEPA PERMIT FORMS**

FORM 7520-6 PROPOSED WELLS UIC PERMIT APPLICATION

FORM 7520-14 PROPOSED WELLS PLUGGING AND ABANDONMENT

## 1.0 PERMIT APPLICATION AND INTRODUCTION

Through the submittal of this application, Powertech (USA) Inc. [Powertech], requests an Area Permit and authorization from the US Environmental Protection Agency (USEPA) to install and operate four to eight non-hazardous Class V disposal wells located at the Dewey-Burdock Project, pursuant to the applicable Underground Injection Control (UIC) regulations. The number of wells is to be determined and is dependent upon well capacity. Powertech requests authorization to inject a total of 300 gallons per minute (gpm) in a maximum of eight Class V disposal wells. These wells are to be located in Custer and Fall River Counties, South Dakota, within the limits of the proposed Class V permit area within the Dewey-Burdock Project boundary. Proposed locations for the first four wells are shown on Figure B-2. The Project is located approximately 13 miles north-northwest of Edgemont, South Dakota, and straddles the area between northern Fall River and southern Custer County line. The project boundary encompasses approximately 10,580 acres (4,282 ha) of mostly private land on either side of County Road 6463 and includes portions of Sections 1-5, 10-12, 14 and 15, Township 7 South, Range 1 East and Sections 20, 21, 27, 28, 29 and 30-35, Township 6 South, Range 1 East. Approximately 240 acres (~2%) (97.1 ha) are under the control of the Bureau of Land Management (BLM) located in portions of Sections 3, 10, 11, and 12. A map identifying the general project location is included as Figure 1.

A completed copy of USEPA UIC 7520-6, "Underground Injection Control Permit Application" for the wells is included in this application, and required attachments to this form are also included in this document. In this application, the initial four planned wells are referred to individually as Dewey-Burdock Disposal Well Nos. 1, 2, 3, and 4, (DW Nos. 1, 2, 3, and 4) or collectively with additional disposal wells as the Dewey-Burdock Disposal Wells. All depths discussed in this application are below ground surface (bgs) unless otherwise noted.

The proposed Powertech facility in South Dakota will operate between four and eight Class V Non-Hazardous Disposal Wells for underground injection of fluids from an in-situ leach (ISL) uranium mining project. Fresh water aquifers in the vicinity of the wells are to be protected by casing and cement. Injected fluids will be delivered to the Minnelusa and Deadwood Formations in separate wells under positive pressure injection through tubing and a packer. The wells are to have one cemented long string protective casing extending into the injection interval. The wellbores are to be perforated completions within the injection interval. The annulus area between the protective casings and injection tubing strings will be filled with inhibited fresh water. Annulus pressure will be continuously monitored to detect any potential leaks in the tubing or casing strings and annulus pressures will be maintained at more than 100 psi above the tubing pressure.

Relevant administrative data regarding the permit are summarized as follows.

|                                   |  |
|-----------------------------------|--|
| <b>Applicant:</b>                 | Powertech (USA) Inc.   |
| <b>State:</b>                     | South Dakota   |
| <b>Counties:</b>                  | Custer and Fall River  |
| <b>Facility Address:</b>          | 310 2 <sup>nd</sup> Avenue<br>Edgemont, SD 57735   |
| <b>Mailing Address:</b>           | 5575 DTC Parkway, Suite 140, Greenwood Village, CO 80111   |
| <b>Location of Planned Wells:</b> | Site 1: NE ¼ of NW ¼ of SW ¼ of Section 2, T7S, R1E<br>DW No. 1: Lat: -103.971938654 Long: 43.469772181<br>DW No. 2: Lat: -103.971859557 Long: 43.4696483743<br><br>Site 2: SE ¼ of NW ¼ of SW ¼ of Section 29, T6S, R1E<br>DW No. 3: Lat: -104.031570321 Long: 43.4971737527<br>DW No. 4: Lat: -104.031436264 Long: 43.4970792287 |

**Location of Additional Wells:** To be determined  
**USEPA ID Nos.:** Dewey-Burdock Disposal Well Nos. 1, 2, 3, 4, and additional wells- TBD  
**Contact:** Mr. Richard Blubaugh, Vice President



United States Environmental Protection Agency  
**Underground Injection Control  
 Permit Application**  
 (Collected under the authority of the Safe Drinking  
 Water Act. Sections 1421, 1422, 40 CFR 144)

| I. EPA ID Number |     |   |
|------------------|-----|---|
|                  | T/A | C |
| U                |     |   |

Read Attached Instructions Before Starting  
**For Official Use Only**

| Application approved | Date received | Permit Number | Well ID | FINDS Number |
|----------------------|---------------|---------------|---------|--------------|
| mo day year          | mo day year   |               |         |              |
|                      |               |               |         |              |

| II. Owner Name and Address                    |  |             |                                | III. Operator Name and Address                |  |             |                                |
|---|--|-------------|--------------------------------|---|--|-------------|--------------------------------|
| Owner Name<br>Powertech (USA) Inc.            |  |             |                                | Owner Name<br>Powertech (USA) Inc.            |  |             |                                |
| Street Address<br>5575 DTC Parkway, Suite 140 |  |             | Phone Number<br>(303) 790-7528 | Street Address<br>5575 DTC Parkway, Suite 140 |  |             | Phone Number<br>(303) 790-7528 |
| City<br>Greenwood Village                     |  | State<br>CO | ZIP CODE<br>80111              | City<br>Greenwood Village                     |  | State<br>CO | ZIP CODE<br>80111              |

| IV. Commercial Facility  | V. Ownership  | VI. Legal Contact  | VII. SIC Codes             |
|--|---|--|----------------------------|
| <input type="checkbox"/> Yes<br><input checked="" type="checkbox"/> No | <input checked="" type="checkbox"/> Private<br><input type="checkbox"/> Federal<br><input type="checkbox"/> Other | <input checked="" type="checkbox"/> Owner<br><input type="checkbox"/> Operator | SIC: 1094<br>NAISC: 212291 |

**VIII. Well Status (Mark "x")**

|                                       |                             |   |   |
|---------------------------------------|-----------------------------|---|---|
| <input type="checkbox"/> A. Operating | Date Started<br>mo day year | <input type="checkbox"/> B. Modification/Conversion | <input checked="" type="checkbox"/> C. Proposed |
|---------------------------------------|-----------------------------|---|---|

**IX. Type of Permit Requested (Mark "x" and specify if required)**

|  |   |                               |                                   |  |
|--|---|-------------------------------|-----------------------------------|--|
| <input type="checkbox"/> A. Individual | <input checked="" type="checkbox"/> B. Area | Number of Existing Wells<br>0 | Number of Proposed Wells<br>4 - 8 | Name(s) of field(s) or project(s)<br>Dewey-Burdock |
|--|---|-------------------------------|-----------------------------------|--|

**X. Class and Type of Well (see reverse)**

| A. Class(es)<br>(enter code(s)) | B. Type(s)<br>(enter code(s)) | C. If class is "other" or type is code 'x,' explain | D. Number of wells per type (if area permit) |
|---------------------------------|-------------------------------|---|--|
| Other                           | N/A                           | Class V, permitted under 40 CFR 144.12              | 4 - 8  |

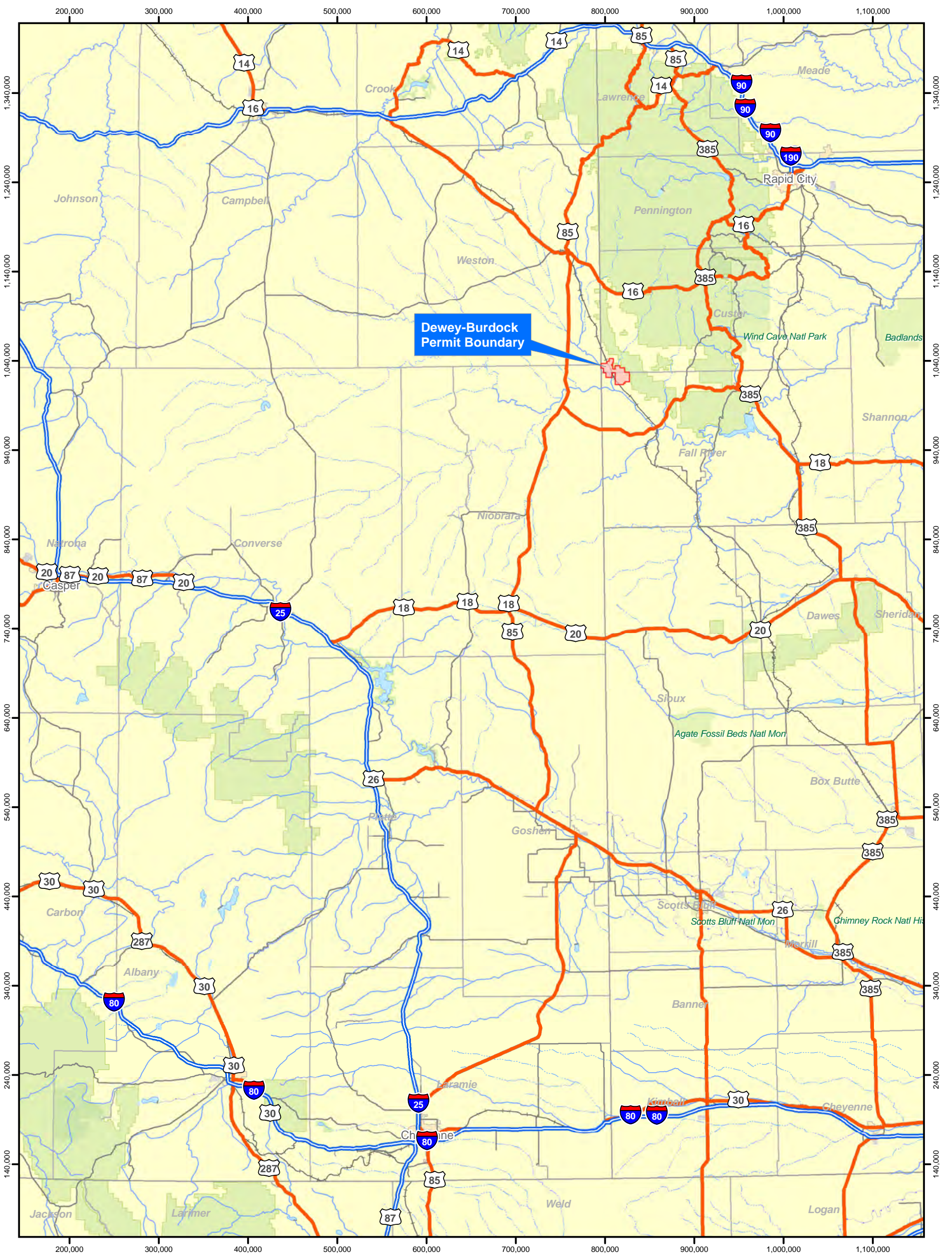
| XI. Location of Well(s) or Approximate Center of Field or Project |     |     |           |     |     |                    |     |       |         |           |      |           | XII. Indian Lands (Mark 'x')   |      |
|---|-----|-----|-----------|-----|-----|--------------------|-----|-------|---------|-----------|------|-----------|--|------|
| Latitude  |     |     | Longitude |     |     | Township and Range |     |       |         |           |      |           | <input type="checkbox"/> Yes<br><input checked="" type="checkbox"/> No |      |
| Deg   | Min | Sec | Deg       | Min | Sec | Sec                | Twp | Range | 1/4 Sec | Feet From | Line | Feet From |  | Line |
| 103   | 59  | 43  | 43        | 28  | 55  | 34                 | 6S  | 1E    | SW      | 93.0      | W    | 1403      | S  |      |

**XIII. Attachments**  
 (Complete the following questions on a separate sheet(s) and number accordingly; see instructions)  
 For Classes I, II, III, (and other classes) complete and submit on a separate sheet(s) Attachments A-U (pp 2-6) as appropriate. Attach maps where required. List attachments by letter which are applicable and are included with your application.

**XIV. Certification**  
 I certify under the penalty of law that I have personally examined and am familiar with the information submitted in this document and all attachments and that, based on my inquiry of those individuals immediately responsible for obtaining the information, I believe that the information is true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment. (Ref. 40 CFR 144.32)

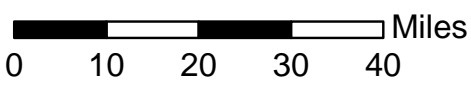
|   |  |
|---|--|
| A. Name and Title (Type or Print)<br>Richard Blubaugh, Vice President - Environmental | B. Phone No. (Area Code and No.)<br>(303) 790-7528 |
| C. Signature  | D. Date Signed                                     |





**Legend**

Dewey-Burdock Permit Boundary





**POWERTECH (USA) INC.**

**Figure 1**  
Site Location Map  
2010 Dewey-Burdock Class V Permit

|                            |                       |
|----------------------------|-----------------------|
| Scale: 1:1,250,000         | Date: March 2010      |
| 2010_DB_Class_V_Fig_01.mxd | By: JLM   Checked: HD |

**Petrotek** 10288 West Chatfield Ave., Suite 201  
Littleton, Colorado 80127-4239 USA  
303-290-9414  
www.petrotek.com



## 2.0 USEPA FORM 7520-6 PERMIT APPLICATION ATTACHMENTS

### 2.A AREA OF REVIEW METHODS

*Give the methods and, if appropriate, the calculations used to determine the size of the area of review (fixed radius or equation). The area of review shall be a fixed radius of ¼-mile from the well bore unless the use of an equation is approved in advance by the Director.*

### RESPONSE

In the meeting held on November 24, 2009, EPA Region 8 instructed Powertech to generally follow Class I standards and approach for this application. As such, the radius of investigation used in this permit request has been based on standard practices applied historically to Class I wells in Region 8. Under Section 146.6 of the UIC regulations (40CFR), the area of review (AOR) for a non-hazardous Class I injection well is defined as either the calculated zone of endangering influence or a fixed radius of not less than one-fourth mile.

The South Dakota Department of Environment and Natural Resources (DENR) has guidance for Class V wells but does not require separate state approval for Class V well installation. The guidelines for Class V wells are outlined in a letter received from DENR which is included as Appendix A.

The critical pressure rise, cone-of-influence (COI), radius of fluid displacement (ROFD) calculations for this permit application are based on the formation parameters derived from the correlation of three separate type logs. The location of these wells is shown on Figure A-1. Type Log #1 (Figure A-2) is from the Earl Darrow #1 (T7S, R1E, Sec 2) which penetrates the top of the Minnelusa and is located within the Dewey-Burdock Project boundary near the well locations of DW Nos. 1 and 2. Type Log #2 (Figure A-3) is from the Lance-Nelson Estate #1 (T7S, R1E, Sec 21) which penetrates the top of the Madison and is located just south of the project boundary. Type Log #3 (Figure A-4), from the #1 West Mule Creek (T39, R61W, Sec 2), penetrates to the top of the Precambrian and is located in eastern Wyoming to the southwest of the Project. This is the closest log available that penetrates the Deadwood Formation. Additionally, tops for shallow formations from the logs of various uranium exploration wells within the Project boundary were used in conjunction with the type logs to determine surface elevation and formation depths at each well site.

DW Nos. 1 and 2 target the Minnelusa and Deadwood Formations, respectively, and are located near the main plant site (Site 1). DW Nos. 3 and 4 target the Minnelusa and Deadwood, respectively, and will be located at Site 2. While formation parameters are expected to be similar at each site, formations are expected to occur at greater depth at Site 2 due to geologic structure. Separate critical pressure rise and COI calculations for the Minnelusa and Deadwood at each site are included in this application and are presented in Tables A-1 through A-4. In addition, ROFD calculations for the Minnelusa and Deadwood are presented in Tables A-5 and A-6, respectively.

Because the calculated ROFD and COI are significantly smaller than the statutory minimum, a fixed radius of 1,320' (¼ mile) has been used for evaluation of all artificial penetrations for Class V injection into the Minnelusa Formation for DW Nos. 1 and 3. Based on COI calculations, a radius of 1,355' has been used for evaluation of all artificial penetrations for Class V injection into the Deadwood Formation for DW Nos. 2 and 4. The Class V permit area has been conservatively defined by applying the maximum calculated AOR of 1,355' as an offset from the Dewey-Burdock Project boundary and the oil and gas wells permitted within that boundary.

In the event that additional disposal wells are required to inject the requested 300 gpm, similar AORs are expected for subsequent Dewey-Burdock Disposal Wells located within the proposed Class V permit area. The input parameters used to calculate the AORs are based on formation parameters derived from limited data and will be verified during the drilling, testing, and completion process. If the input parameters that have been used are found to yield projections that are insufficiently conservative, the AORs will be recalculated.

The COI for injection is defined as that area around a well within which increased injection zone pressures caused by injection could be sufficient to drive fluids into an underground source of drinking water (USDW). The pathway for this theoretical fluid movement is assumed to be a hypothetical, open abandoned well, which penetrates the confining zone for injection. Information used in the following calculations has been estimated from available geophysical well logs and will be verified through formation testing during the drilling process.

### **Critical Pressure Rise**

For this permit application, three critical pressure rise calculations are required at each site. One is applied for the rise from the Minnelusa to the Unkpapa/Sundance, one for the rise from the Minnelusa to the Madison, and one for the rise from the Deadwood to the Madison.

To calculate the COI, a value must first be assigned for the pressure increase in the injection interval that would be sufficient to cause injection zone brine to rise in a hypothetical open pathway to the base of the lowermost USDW. This applies individually to the rise from the Minnelusa (injection zone) to the Unkpapa/Sundance (USDW) and for rise from the Deadwood (injection zone) to the Madison (USDW). The COI will also be applied to the transfer of injection zone brine from the base of the effective Minnelusa in a hypothetical open pathway down to the top of the Madison Formation. This critical pressure rise,  $P_c$ , is assigned as indicated in Figure A-5.

The pressure required at the top of the injection interval to support injection zone brine in the configuration indicated is, in psi units:

$$P = 0.433 [y_B D_B + y_w (D_w - L)]$$

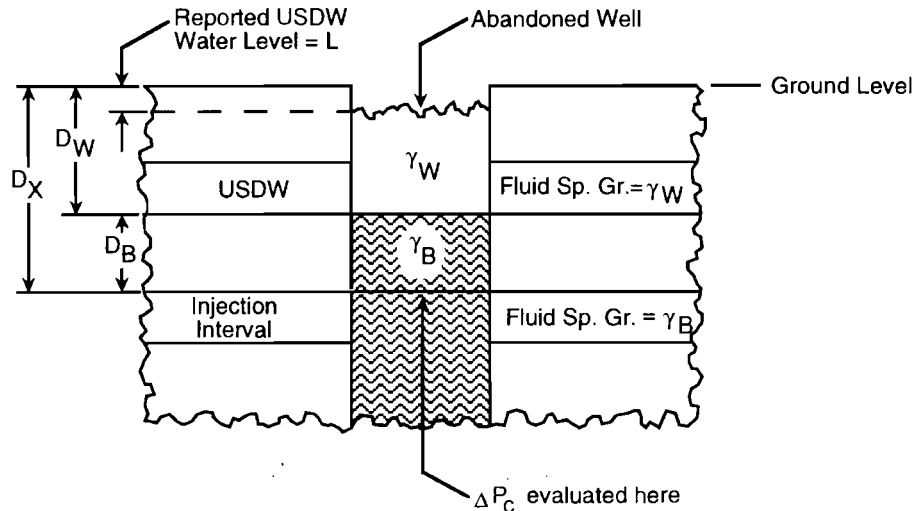
where:  $D_B = D_x - D_w$

and the pressure rise is then:

$$P_c = 0.433 [y_B D_B + y_w (D_w - L)] - P_o$$

where  $P_o$  is the original, pre-injection value for pressure at the top of the injection interval expressed in psi units.

**FIGURE A-5 CRITICAL PRESSURE RISE**



**MINNELUSA TO UNKPAPA/SUNDANCE AND MINNELUSA TO MADISON FOR DW NO. 1 – SITE 1**

Minnelusa – Unkpapa/Sundance

Original pressure in the Minnelusa has been calculated based on a depth to water of 1,415' above top of the Minnelusa from USGS potentiometric maps (Figure D-14, Driscoll et al., 2002). For the estimated top of the injection interval of 1,615' (See Response F, Table F-2), a gradient of 0.433 psi/ft \* 1.008 (SG of approximately 15,000 mg/l TDS brine) yields a pressure of 617.6 psi at the top of the Minnelusa (1,615'). The same gradient applied to the effective base of the Injection Zone at 2,205 yields a pressure 875.1 psi. The effective base refers to the lowermost zone of effective porosity in the Minnelusa that will be targeted for injection in DW No. 1 as discussed in Section 2.F of this document.

In assigning the critical pressure rise and calculating the cone-of-influence (Tables A-1 and A-3) at this site, the base of the overlying USDW, the Unkpapa/Sundance, is assigned as 920', as discussed in Response 2.D of this document. The potentiometric surface of Unkpapa/Sundance near the Dewey-Burdock Project is projected to be approximately 29 feet above ground surface (Figure D-14a, Powertech 2008). Therefore, in these calculations, it is assumed that the water table in the Unkpapa/Sundance is at approximately 589 feet above the top of the formation. The result is a calculated critical pressure rise for Minnelusa to Unkpapa/Sundance of 97.1 psi (Table A-1).

The values in Table A-1 were used in the pressure rise equation to compute the critical pressure rise for Minnelusa to Unkpapa/Sundance as follows:

$$P_c = 0.433[1.008(1,615-920) + 1.001(920-(-29))] - 617.6 \text{ psi}$$

or:

$$P_c = 97.1 \text{ psi}$$

### Minnelusa - Madison

The top of the underlying USDW is the Madison Formation at 2,765' as discussed in Response 2.D of this document. Original pressure in the Madison has been calculated based on an artesian aquifer condition with a water level of approximately 200' above ground surface. This head is based on historical water well data for the City of Edgemont water wells completed in the Madison Formation (Appendix D). Based on an estimated shut-in pressure of 150 psi and a minimum surface elevation of 3,450', the potentiometric surface of the Madison at Edgemont is 3,745' (345' above ground surface). It is noted that surface elevation at Edgemont wells may be as high as 3,650'. Given the elevation increase of approximately 100' to 300' from Edgemont to the Dewey-Burdock Project, it is reasonable to assume a potentiometric level of approximately 3,900' AMSL (~200' above ground surface) at Dewey-Burdock. USGS potentiometric maps for this formation are regional and based on little (if any) local data (Figure D-10, Driscoll et al., 2002). The result is a calculated critical pressure rise for the Minnelusa to Madison of 165.6 psi (Table A-1). It is noted that formation parameters have been estimated from available data and will be verified through formation testing during the drilling process.

The values in Table A-1 were used in the pressure rise equation to compute the critical pressure rise for Minnelusa to top of Madison as follows:

$$P_c = 0.433[1.008(2,205-2,765) + 1.001(2,765-(-200))] - 875.1 \text{ psi}$$

or:

$$P_c = 165.6 \text{ psi}$$

### **Cone-of-Influence**

Based on the calculated value for the critical pressure rise, the cone-of-influence can be calculated for DW No.1 over a ten-year period of injection. At DW No. 1 there is projected to be a 13.2' cone-of-influence for continuous injection at a rate of 75 gpm (2,571 bwpd) in the Minnelusa Formation (Table A-2). This is the value at which pressure at distance intersects the critical pressure rise of 97.1 psi from the Minnelusa to the Unkpapa/Sundance (Figure A-6). Since the critical pressure rise for the Minnelusa to the over-pressured Madison is never intersected, even at the well bore, there is no COI and no potential exists for contamination of the Madison. As such, the fixed radius of 1,320' (¼ mile) will be used for the Minnelusa Formation at Site 1. Pressure rise has been evaluated in an infinite acting reservoir with a line source well using the log-approximation of the radial flow diffusivity equation (Lee, 1982).

$$dP = -70.6 Bq\mu / kh * \ln ( [ 1,688 \phi \mu c_r^2 / kt ] -2s)$$

where the values listed in Table A-3 have been assigned based on site-specific information.

Calculations for pressure rise due to ten years of injection have been based on a rate of 75 gpm. Well capacities will be verified during the drilling, testing, and completion process.

### **MINNELUSA TO UNKPAPA/SUNDANCE AND MINNELUSA TO MADISON FOR DW NO. 3 – SITE 2**

#### Minnelusa – Unkpapa/Sundance

Original pressure in the Minnelusa has been calculated based on a depth to water of 1,750' above the top of the Minnelusa from USGS potentiometric maps (Figure D-14, Driscoll et al., 2002). For the estimated top of the injection interval of 1,950' (See Response F, Table F-2), a gradient of 0.433

psi/ft \* 1.008 (SG of approximately 15,000 mg/l TDS brine) yields a pressure of 763.8 psi at the top of the Minnelusa. The same gradient applied to the effective base of the Injection Zone at 2,540 yields a pressure 1,021.3 psi. (Table A-2). The effective base refers to the lowermost porous zone that will be targeted for injection as discussed in Section 2.F of this document.

In assigning the critical pressure rise and calculating the cone-of-influence (Tables A-2 and A-3) at this site, the base of the overlying USDW, the Unkpapa/Sundance, is assigned as 1,255', as discussed in Response 2.D of this document. The lowest potentiometric surface near the Dewey-Burdock Project is projected to be approximately 29 feet above ground surface (Figure D-14a, Powertech 2008). Therefore, in these calculations, it is assumed that the water table in the Unkpapa/Sundance is at approximately 924' above the top of the formation. The result is a calculated critical pressure rise for Minnelusa to Unkpapa/Sundance of 96.1 psi (Table A-2).

The values in Table A-2 were used in the pressure rise equation to compute the critical pressure rise for Minnelusa to Unkpapa/Sundance as follows:

$$P_c = 0.433[1.008(1,950-1,255) + 1.001(1,255-(-29))] - 763.8 \text{ psi}$$

or:

$$P_c = 96.1 \text{ psi}$$

#### Minnelusa - Madison

The top of the underlying USDW is the Madison Formation at 3,100' as discussed in Response 2.D of this document. Original pressure in the Madison has been calculated based on an artesian aquifer condition with a water level of approximately 200' above ground surface. This head is based on historical water well data for the City of Edgemont water wells completed in the Madison Formation (Appendix D). Based on an estimated shut-in pressure of 150 psi and a minimum surface elevation of 3,450', the potentiometric surface of the Madison at Edgemont is 3,745' (345' above ground surface). It is noted that surface elevation at Edgemont wells may be as high as 3,650'. Given the elevation increase of approximately 100' to 300' from Edgemont to the Dewey-Burdock Project, it is reasonable to assume a potentiometric level of approximately 3,900' AMSL (~200' above ground surface) at Dewey-Burdock. USGS potentiometric maps for this formation are regional and based on little (if any) local data (Figure D-10, Driscoll et al., 2002). The result is a calculated critical pressure rise for the Minnelusa to Madison of 164.6 psi (Table A-2). It is noted that formation parameters have been estimated from available data and will be verified through formation testing during the drilling process.

The values in Table A-2 were used in the pressure rise equation to compute the critical pressure rise for Minnelusa to Madison as follows:

$$P_c = 0.433[1.008(2,540-3,100) + 1.001(3,100-(-200))] - 1,021.3 \text{ psi}$$

or:

$$P_c = 164.6 \text{ psi}$$

#### **Cone-of-Influence**

Based on the calculated value for the critical pressure rise, the cone-of-influence can be calculated for DW No. 3 over a ten-year period of injection. At DW No. 3, there is projected to be a 14.4' cone-of-influence for continuous injection at a rate of 75 gpm (2,571 bwpd) in the Minnelusa Formation (Table A-3). This is the value at which pressure at distance intersects the critical pressure rise of 96.1 psi from the Minnelusa to the Unkpapa/Sundance (Figure A-6). Since the critical pressure rise for the Minnelusa to the over-pressured Madison is never intersected, even at the well bore, there is

no COI and no potential exists for contamination of the Madison. As such, the fixed radius of 1,320' (1/4 mile) will be used. Pressure rise has been evaluated in an infinite acting reservoir with a line source well using the log-approximation of the radial flow diffusivity equation (Lee, 1982).

$$dP = -70.6 Bq\mu /kh * \ln ( [ 1,688 \phi \mu c_r r^2 /kt ] -2s)$$

where the values listed in Table A-3 have been assigned based on site-specific information.

Calculations for pressure rise due to ten years of injection have been based on a rate of 75 gpm. Well capacities will be verified during the drilling, testing, and completion process.

### **DEADWOOD TO MADISON FOR DW NO. 2 – SITE 1**

Original pressure in the Deadwood has been calculated based on an estimated formation fluid level of 2,900' above the top of the Deadwood. For the estimated top of the injection interval of 3,100' (See Response F, Table F-2), a gradient of 0.433 psi/ft \* 1.008 (SG of 15,000 mg/l TDS brine) yields a pressure of 1,265.7 psi at the top of the Deadwood.

In assigning the critical pressure rise and calculating the cone-of-influence (Tables A-1 and A-4) at this site, the base of the overlying USDW, the Madison Formation, is assigned as 3,060', as discussed in Response 2.D of this document. Original pressure in the Madison has been calculated based on an artesian aquifer condition with a water level of approximately 200' above ground surface. This head is based on historical water well data for the City of Edgemont water wells completed in the Madison Formation (Appendix D). Based on an estimated shut-in pressure of 150 psi and a minimum surface elevation of 3,450', the potentiometric surface of the Madison at Edgemont is 3,745' (345' above ground surface). It is noted that surface elevation at Edgemont wells may be as high as 3,650'. Given the elevation increase of approximately 100' to 300' from Edgemont to the Dewey-Burdock Project, it is reasonable to assume a potentiometric level of approximately 3,900' AMSL (~200' above ground surface) at Dewey-Burdock. USGS potentiometric maps for this formation are regional and based on little (if any) local data (Figure D-10, Driscoll et al., 2002). The result is a calculated critical pressure rise for the Minnelusa to Madison of 164.7 psi (Table A-1). It is noted that formation parameters have been estimated from available data and will be verified through formation testing during the drilling process.

The values in Table A-1 were used in the pressure rise equation to compute the critical pressure rise for Deadwood to Madison as follows:

$$P_c = 0.433[1.008(3,100-3,060) + 1.001(3,060-(-200))] - 1,265.7 \text{ psi}$$

or:

$$P_c = 164.7 \text{ psi}$$

### **Cone-of-Influence**

Based on the calculated value for the critical pressure rise, the cone-of-influence can be calculated for the DW No. 2 over a ten-year period of injection. At DW No. 2, there is projected to be a 1,210' cone-of-influence for continuous injection at a rate of 75 gpm (2,571 bwpd) in the Deadwood Formation (Table A-4). This is the value at which pressure at distance intersects the critical pressure rise of 164.7 psi from the Deadwood to the Madison (Figure A-7). Pressure rise has been evaluated in an infinite acting reservoir with a line source well using the log-approximation of the radial flow diffusivity equation (Lee, 1982).

$$dP = -70.6 Bq\mu /kh * \ln ( [ 1,688 \phi \mu c_r r^2 /kt ] -2s)$$

where the values listed in Table A-4 have been assigned based on site-specific information.

Calculations for pressure rise due to ten years of injection have been based on a rate of 75 gpm. Well capacities will be verified during the drilling, testing, and completion process.

#### **DEADWOOD TO MADISON FOR DW NO. 4 – SITE 2**

Original pressure in the Deadwood has been calculated based on an estimated formation fluid level of 3,235' above the top of the Deadwood. For the estimated top of the injection interval of 3,435' (See Response F), a gradient of 0.433 psi/ft \* 1.008 (SG of 15,000 mg/l TDS brine) yields a pressure of 1,412.0 psi at the top of the Deadwood.

In assigning the critical pressure rise and calculating the cone-of-influence (Tables A-2 and a-4) at this site, the base of the overlying USDW, the Madison Formation, is assigned as 3,395', as discussed in Response 2.D of this document. Original pressure in the Madison has been calculated based on an artesian aquifer condition with a water level of approximately 200' above ground surface. This head is based on historical water well data for the City of Edgemont water wells completed in the Madison Formation (Appendix D). Based on an estimated shut-in pressure of 150 psi and a minimum surface elevation of 3,450', the potentiometric surface of the Madison at Edgemont is 3,745' (345' above ground surface). It is noted that surface elevation at Edgemont wells may be as high as 3,650'. Given the elevation increase of approximately 100' to 300' from Edgemont to the Dewey-Burdock Project, it is reasonable to assume a potentiometric level of approximately 3,900' AMSL (~200' above ground surface) at Dewey-Burdock. USGS potentiometric maps for this formation are regional and based on little (if any) local data (Figure D-10, Driscoll et al., 2002). The result is a calculated critical pressure rise for the Minnelusa to Madison of 163.7 psi (Table A-2). It is noted that formation parameters have been estimated from available data and will be verified through formation testing during the drilling process.

The values in Table A-2 were used in the pressure rise equation to compute the critical pressure rise for Deadwood to Madison as follows:

$$P_c = 0.433[1.008(3,435-3,395) + 1.001(3,395-(-200))] - 1,412.0 \text{ psi}$$

or:

$$P_c = 163.7 \text{ psi}$$

#### **Cone-of-Influence**

Based on the calculated value for the critical pressure rise, the cone-of-influence can be calculated for the DW No. 2 over a ten-year period of injection. At DW No. 4, there is projected to be a 1,242' cone-of-influence for continuous injection at a rate of 75 gpm (2,571 bwpd) in the Deadwood Formation (Table A-4). This is the value at which pressure at distance intersects the critical pressure rise of 163.7 psi from the Deadwood to the Madison (Figure A-7). Pressure rise has been evaluated in an infinite acting reservoir with a line source well using the log-approximation of the radial flow diffusivity equation (Lee, 1982).

$$dP = -70.6 Bq\mu / kh * \ln ( [ 1,688 \phi \mu c_r r^2 / kt ] -2s)$$

where the values listed in Table A-4 have been assigned based on site-specific information.

Calculations for pressure rise due to ten years of injection have been based on a rate of 75 gpm. Well capacities will be verified during the drilling, testing, and completion process.



## **Radius of Fluid Displacement**

### Minnelusa

The same formation parameters for each formation that were used in the COI calculations were used to calculate the ROFD. Using a porosity of 21% and an effective thickness of 164', the calculated ROFD is 698' after 10 years of constant rate injection at 75 gpm. The effect of an estimated hydraulic gradient of 10 ft/mile alters the maximum ROFD by 8.12' which yields a total calculated ROFD of approximately 706' (Table A-5). The ROFD in the Minnelusa is presented on Figure B-2.

### Deadwood

Using a porosity of 11% and an effective thickness of 85', the calculated ROFD is 1,339' after 10 years of constant rate injection at 75 gpm. The effect of an estimated hydraulic gradient of 10 ft/mile alters the maximum ROFD by 15.50' which yields a total calculated ROFD of approximately 1,355' (Table A-6). The ROFD in the Deadwood is presented on Figure B-2a.

## **Final AORs**

The calculated COIs for DW Nos. 1, 2, 3, and 4 are 13.2', 1,210', 14.4', and 1,242', respectively. The distances for DW Nos. 1 and 3 are less than the calculated ROFDs for the Minnelusa (706') and less than a fixed radius of ¼ mile or 1,320'. As such, a radius of 1,320' has been used for evaluation of all artificial penetrations for Class V injection into the Minnelusa Formation for DW No. 1 and DW No. 3 (Figure B-2).

The calculated COIs for DW Nos. 2 and 4 are less than the calculated ROFDs for the Deadwood (1,355') and greater than a fixed radius of ¼ mile or 1,320'. As such, a radius of 1,355' has been used for DW No. 2 and DW No. 4 for evaluation of all artificial penetrations for Class V injection into the Deadwood Formation (Figure B-2a). Figure B-2b presents the final AORs of the four planned wells relative to the Class V permit area and oil and gas wells near the project. The Class V permit area is defined conservatively by applying the maximum calculated AOR of 1,355' as an offset from the Dewey-Burdock Project boundary and the oil and gas wells permitted within that boundary.

The input parameters used to calculate the AORs are based on formation parameters derived from limited data and will be verified during the drilling, testing, and completion process. If the input parameters that have been used are found to yield projections that are insufficiently conservative, the AORs will be recalculated.

## **Pressure Rise at the Dewey Fault**

The Dewey Fault shown on Figure B-2b is located in excess of 4,000' to the northwest of the nearest corner of the proposed Class V permit area. While some authors have mapped it as dipping to the southeast, it is shown at the same location relative to the Dewey-Burdock Project at surface and at depth (Figures D-1, D-8, D-10, D-14, and D-15). As such, it is more likely a near vertical fault in proximity to the site. The pressure rise at a distance of 4,000' due to injection in the Minnelusa would be approximately 34 psi. This is less than the calculated critical pressure rise of 96.1 psi (Minnelusa to Unkpapa/Sundance) and 164.6 psi (Minnelusa to Madison). The pressure rise at a distance of 4,000' due to injection into the Deadwood would be approximately 119 psi. This is less than the calculated critical pressure rise of 163.7 psi necessary to transmit fluid from the Deadwood to the Madison along any hypothetical open pathway. It can thus be concluded that the Dewey Fault could not act as a conduit for fluid to rise to a USDW due to injection into the Minnelusa or

Deadwood in the vicinity of the proposed Class V permit area.

**TABLE A-1 Critical Pressure Rise - Site 1**

| $P_c = 0.433(Y_b D_b + Y_w(D_w - L)) - P_o$ |       |     | Inj. Zone<br>DTW | Yb       | Confining<br>Zone Db | SG of<br>USDW<br>Yw | Top Inj.<br>Zone<br>Dx | Base/Top<br>Inj. Zone<br>Dw | USDW<br>DTW<br>L | Inj. Zone<br>Po |
|---|-------|-----|------------------|----------|----------------------|---------------------|------------------------|-----------------------------|------------------|-----------------|
|   |       |     | (ft; bgs)        | (Inj. Z) | (feet; bgs)          | (USDW)              | (feet; bgs)            | (feet; bgs)                 | (feet; bgs)      | (psi)           |
| <b>Minnelusa to Unkpapa/Sundance</b>        |       |     | 200              | 1.008    | 695                  | 1.001               | 1615                   | 920                         | -29              | 617.6           |
| Pc =  | 97.1  | psi |                  |          |                      |                     |                        |                             |                  |                 |
| <b>Minnelusa to Madison</b>                 |       |     | 200              | 1.008    | -560                 | 1.001               | 2205                   | 2765                        | -200             | 875.1           |
| Pc =  | 165.6 | psi |                  |          |                      |                     |                        |                             |                  |                 |
| <b>Deadwood to Madison</b>                  |       |     | 200              | 1.008    | 40                   | 1.001               | 3100                   | 3060                        | -200             | 1,265.7         |
| Pc =  | 164.7 | psi |                  |          |                      |                     |                        |                             |                  |                 |

Po calculated based on a depth to water of 1,400' above top of Minnelusa; fluid gradient of Minnelusa and Deadwood = 0.433 psi/ft x 1.008 (SG)

TABLE A-2 Critical Pressure Rise - Site 2

| Pc=0.433(YbDb+Yw(Dw-L))-Po           |       |     |  | Inj. Zone DTW (ft;bgs) | Yb (Inj. Z) | Confining Zone Db (feet; bgs) | SG of USDW Yw (USDW) | Top Inj. Zone Dx (feet; bgs) | Base/Top Inj. Zone Dw (feet; bgs) | USDW DTW L (feet; bgs) | Inj. Zone Po (psi) |
|--------------------------------------|-------|-----|--|------------------------|-------------|-------------------------------|----------------------|------------------------------|-----------------------------------|------------------------|--------------------|
| <b>Minnelusa to Unkpapa/Sundance</b> |       |     |  | 200                    | 1.008       | 695                           | 1.001                | 1950                         | 1255                              | -29                    | 763.8              |
| Pc =                                 | 96.1  | psi |  |                        |             |                               |                      |                              |                                   |                        |                    |
| <b>Minnelusa to Madison</b>          |       |     |  | 200                    | 1.008       | -560                          | 1.001                | 2540                         | 3100                              | -200                   | 1,021.3            |
| Pc =                                 | 164.6 | psi |  |                        |             |                               |                      |                              |                                   |                        |                    |
| <b>Deadwood to Madison</b>           |       |     |  | 200                    | 1.008       | 40                            | 1.001                | 3435                         | 3395                              | -200                   | 1,412.0            |
| Pc =                                 | 163.7 | psi |  |                        |             |                               |                      |                              |                                   |                        |                    |

Po calculated based on a depth to water of 1,400' above top of Minnelusa; fluid gradient of Minnelusa and Deadwood = 0.433 psi/ft x 1.008 (SG)

TABLE A-3 Calculated Pressure Rise vs. Distance (Diffusivity Equation) - Minnelusa Formation

Injection Rate (gpm) **75**

Based on Equation 1.11 (Lee, 1982; P. 5)

$$dp = -70.6(qBu/kh)[\ln(1,688.388*por*u*ct*rw^2/kt)-2s]$$

Where

- dp = pressure differential
- q = flowrate (STB/d)
- B = formation volume factor (RB/STB)
- u = viscosity (cp)
- k = permeability (md)
- h = reservoir thickness (feet)
- por = formation effective porosity (percent)
- ct = total matrix and fluid compressibility (1/psi)
- rw = radius (feet)
- t = injection time (hours)
- s = skin factor (units)

|                       |   |             |
|-----------------------|---|-------------|
| Solve psi             |   |             |
| 2,571.43 bbl/d        |   |             |
| <b>1.01</b> RB/STB    |   |             |
| <b>0.74</b> cp        |   |             |
| <b>150</b> md         |   |             |
| <b>164</b> feet       |   |             |
| <b>0.21</b> fraction  |   |             |
| <b>6.50E-06</b> psi-1 |   |             |
| Variable feet         |   |             |
| <b>87660.0</b> hours  | = | 10.00 years |
| <b>0.0</b>            |   |             |

- Term 1 -70.6(qBu/kh)
- Term 2 (por\*u\*ct\*rw^2/kt)

Injection Rate (gpm) = 75

$$dp = \text{Term 1} * \ln(1688.388 * \text{Term 2})$$

|         | Radius (ft) | Term 1   | Term 2     | $\ln(\text{term 2}) - 2s$ | dp (psi) |   |
|---------|-------------|----------|------------|---------------------------|----------|---|
| rw      | 0.26042     | -5.51566 | 5.2098E-15 | -25.45671                 | 140.4    | Minn-Madison NO COI At 165.6 (DW No. 1) or 164.6 (DW No. 3) |
| no skin | 0.5         | -5.51566 | 1.9205E-14 | -24.15208                 | 133.2    |   |
|         | 1           | -5.51566 | 7.6820E-14 | -22.76579                 | 125.6    |   |
|         | 5           | -5.51566 | 1.9205E-12 | -19.54691                 | 107.8    |   |
|         | 13.2        | -5.51566 | 1.3385E-11 | -17.60535                 | 97.1     | Minn-Unkpapa/Sundance Pc=97.1 psi (DW No. 1)                |
|         | 14.4        | -5.51566 | 1.5929E-11 | -17.43133                 | 96.1     | Minn-Unkpapa/Sundance Pc=96.1 psi (DW No. 3)                |
|         | 22.6        | -5.51566 | 3.9236E-11 | -16.52989                 | 91.2     |   |
|         | 25          | -5.51566 | 4.8012E-11 | -16.32804                 | 90.1     |   |
|         | 35          | -5.51566 | 9.4104E-11 | -15.65509                 | 86.3     |   |
|         | 48.5        | -5.51566 | 1.8070E-10 | -15.00266                 | 82.7     |   |
|         | 50.5        | -5.51566 | 1.9591E-10 | -14.92184                 | 82.3     |   |
|         | 75          | -5.51566 | 4.3211E-10 | -14.13081                 | 77.9     |   |

TABLE A-3 Calculated Pressure Rise vs. Distance (Diffusivity Equation) - Minnelusa Formation

|      |          |            |           |      |
|------|----------|------------|-----------|------|
| 100  | -5.51566 | 7.6820E-10 | -13.55545 | 74.8 |
| 125  | -5.51566 | 1.2003E-09 | -13.10916 | 72.3 |
| 150  | -5.51566 | 1.7284E-09 | -12.74452 | 70.3 |
| 172  | -5.51566 | 2.2726E-09 | -12.47080 | 68.8 |
| 200  | -5.51566 | 3.0728E-09 | -12.16915 | 67.1 |
| 225  | -5.51566 | 3.8890E-09 | -11.93359 | 65.8 |
| 250  | -5.51566 | 4.8012E-09 | -11.72287 | 64.7 |
| 275  | -5.51566 | 5.8095E-09 | -11.53225 | 63.6 |
| 300  | -5.51566 | 6.9138E-09 | -11.35822 | 62.6 |
| 325  | -5.51566 | 8.1141E-09 | -11.19814 | 61.8 |
| 350  | -5.51566 | 9.4104E-09 | -11.04992 | 60.9 |
| 375  | -5.51566 | 1.0803E-08 | -10.91194 | 60.2 |
| 400  | -5.51566 | 1.2291E-08 | -10.78286 | 59.5 |
| 425  | -5.51566 | 1.3876E-08 | -10.66161 | 58.8 |
| 450  | -5.51566 | 1.5556E-08 | -10.54729 | 58.2 |
| 500  | -5.51566 | 1.9205E-08 | -10.33657 | 57.0 |
| 625  | -5.51566 | 3.0008E-08 | -9.89028  | 54.6 |
| 750  | -5.51566 | 4.3211E-08 | -9.52564  | 52.5 |
| 1000 | -5.51566 | 7.6820E-08 | -8.95028  | 49.4 |
| 1250 | -5.51566 | 1.2003E-07 | -8.50399  | 46.9 |
| 1500 | -5.51566 | 1.7284E-07 | -8.13935  | 44.9 |
| 1830 | -5.51566 | 2.5726E-07 | -7.74165  | 42.7 |
| 2020 | -5.51566 | 3.1345E-07 | -7.54408  | 41.6 |
| 2250 | -5.51566 | 3.8890E-07 | -7.32842  | 40.4 |
| 2400 | -5.51566 | 4.4248E-07 | -7.19934  | 39.7 |
| 3000 | -5.51566 | 6.9138E-07 | -6.75305  | 37.2 |
| 3500 | -5.51566 | 9.4104E-07 | -6.44475  | 35.5 |
| 4000 | -5.51566 | 1.2291E-06 | -6.17769  | 34.1 |
| 4500 | -5.51566 | 1.5556E-06 | -5.94212  | 32.8 |
| 5280 | -5.51566 | 2.1416E-06 | -5.62243  | 31.0 |
| 6000 | -5.51566 | 2.7655E-06 | -5.36676  | 29.6 |
| 6600 | -5.51566 | 3.3463E-06 | -5.17614  | 28.5 |
| 6700 | -5.51566 | 3.4484E-06 | -5.14606  | 28.4 |
| 6800 | -5.51566 | 3.5521E-06 | -5.11643  | 28.2 |
| 6900 | -5.51566 | 3.6574E-06 | -5.08723  | 28.1 |
| 7000 | -5.51566 | 3.7642E-06 | -5.05846  | 27.9 |
| 7100 | -5.51566 | 3.8725E-06 | -5.03009  | 27.7 |
| 7200 | -5.51566 | 3.9823E-06 | -5.00212  | 27.6 |
| 7300 | -5.51566 | 4.0937E-06 | -4.97453  | 27.4 |
| 7400 | -5.51566 | 4.2066E-06 | -4.94732  | 27.3 |
| 7500 | -5.51566 | 4.3211E-06 | -4.92047  | 27.1 |
| 7600 | -5.51566 | 4.4371E-06 | -4.89398  | 27.0 |
| 7700 | -5.51566 | 4.5546E-06 | -4.86784  | 26.8 |
| 7800 | -5.51566 | 4.6737E-06 | -4.84203  | 26.7 |
| 7900 | -5.51566 | 4.7943E-06 | -4.81655  | 26.6 |
| 8000 | -5.51566 | 4.9164E-06 | -4.79139  | 26.4 |

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TABLE A-3 Calculated Pressure Rise vs. Distance (Diffusivity Equation) - Minnelusa Formation

|       |          |            |          |      |
|-------|----------|------------|----------|------|
| 8100  | -5.51566 | 5.0401E-06 | -4.76655 | 26.3 |
| 8200  | -5.51566 | 5.1653E-06 | -4.74201 | 26.2 |
| 8300  | -5.51566 | 5.2921E-06 | -4.71777 | 26.0 |
| 8400  | -5.51566 | 5.4204E-06 | -4.69381 | 25.9 |
| 8500  | -5.51566 | 5.5502E-06 | -4.67015 | 25.8 |
| 9000  | -5.51566 | 6.2224E-06 | -4.55583 | 25.1 |
| 10000 | -5.51566 | 7.6820E-06 | -4.34511 | 24.0 |
| 10560 | -5.51566 | 8.5664E-06 | -4.23613 | 23.4 |
| 11000 | -5.51566 | 9.2952E-06 | -4.15449 | 22.9 |

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TABLE A-4 Calculated Pressure Rise vs. Distance (Diffusivity Equation) - Deadwood Formation

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Injection Rate (gpm) **75**

Based on Equation 1.11 (Lee, 1982; P. 5)

$$dp = -70.6(qBu/kh)[\ln(1,688.388*por*u*ct*rw^2/kt)-2s]$$

Where

- dp = pressure differential
- q = flowrate (STB/d)
- B = formation volume factor (RB/STB)
- u = viscosity (cp)
- k = permeability (md)
- h = reservoir thickness (feet)
- por = formation effective porosity (percent)
- ct = total matrix and fluid compressibility (1/psi)
- rw = radius (feet)
- t = injection time (hours)
- s = skin factor (units)

|                       |   |             |
|-----------------------|---|-------------|
| Solve psi             |   |             |
| 2,571.43 bbl/d        |   |             |
| <b>1.01</b> RB/STB    |   |             |
| <b>0.67</b> cp        |   |             |
| <b>75</b> md          |   |             |
| <b>85</b> feet        |   |             |
| <b>0.11</b> fraction  |   |             |
| <b>7.00E-06</b> psi-1 |   |             |
| Variable feet         |   |             |
| <b>87660.0</b> hours  | = | 10.00 years |
| <b>0.0</b>            |   |             |

Term 1    -70.6(qBu/kh)

Term 2    (por\*u\*ct\*rw^2/kt)

Injection Rate (gpm)                      75

$$dp = \text{Term 1} * \ln(1688.388 * \text{Term 2})$$

|         | Radius (ft) | Term 1    | Term 2     | [ln (term 2) - 2s] | dp (psi) |
|---------|-------------|-----------|------------|--------------------|----------|
| rw      | 0.26042     | -19.27060 | 5.3217E-15 | -25.43545          | 490.2    |
| no skin | 0.5         | -19.27060 | 1.9617E-14 | -24.13083          | 465.0    |
|         | 1           | -19.27060 | 7.8470E-14 | -22.74453          | 438.3    |
|         | 5           | -19.27060 | 1.9617E-12 | -19.52566          | 376.3    |
|         | 10          | -19.27060 | 7.8470E-12 | -18.13936          | 349.6    |
|         | 15          | -19.27060 | 1.7656E-11 | -17.32843          | 333.9    |
|         | 22.6        | -19.27060 | 4.0079E-11 | -16.50863          | 318.1    |
|         | 25          | -19.27060 | 4.9044E-11 | -16.30678          | 314.2    |
|         | 35          | -19.27060 | 9.6126E-11 | -15.63384          | 301.3    |

2.7-L-27

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TABLE A-4 Calculated Pressure Rise vs. Distance (Diffusivity Equation) - Deadwood Formation

|      |           |            |           |       |   |
|------|-----------|------------|-----------|-------|---|
| 48.5 | -19.27060 | 1.8458E-10 | -14.98140 | 288.7 |   |
| 50.5 | -19.27060 | 2.0012E-10 | -14.90059 | 287.1 |   |
| 75   | -19.27060 | 4.4139E-10 | -14.10956 | 271.9 |   |
| 100  | -19.27060 | 7.8470E-10 | -13.53419 | 260.8 |   |
| 125  | -19.27060 | 1.2261E-09 | -13.08790 | 252.2 |   |
| 150  | -19.27060 | 1.7656E-09 | -12.72326 | 245.2 |   |
| 172  | -19.27060 | 2.3215E-09 | -12.44954 | 239.9 |   |
| 200  | -19.27060 | 3.1388E-09 | -12.14790 | 234.1 |   |
| 225  | -19.27060 | 3.9725E-09 | -11.91233 | 229.6 |   |
| 250  | -19.27060 | 4.9044E-09 | -11.70161 | 225.5 |   |
| 275  | -19.27060 | 5.9343E-09 | -11.51099 | 221.8 |   |
| 300  | -19.27060 | 7.0623E-09 | -11.33697 | 218.5 |   |
| 325  | -19.27060 | 8.2884E-09 | -11.17688 | 215.4 |   |
| 350  | -19.27060 | 9.6126E-09 | -11.02867 | 212.5 |   |
| 375  | -19.27060 | 1.1035E-08 | -10.89068 | 209.9 |   |
| 400  | -19.27060 | 1.2555E-08 | -10.76160 | 207.4 |   |
| 425  | -19.27060 | 1.4174E-08 | -10.64035 | 205.0 |   |
| 450  | -19.27060 | 1.5890E-08 | -10.52604 | 202.8 |   |
| 500  | -19.27060 | 1.9617E-08 | -10.31532 | 198.8 |   |
| 625  | -19.27060 | 3.0652E-08 | -9.86903  | 190.2 |   |
| 715  | -19.27060 | 4.0116E-08 | -9.59997  | 185.0 |   |
| 1000 | -19.27060 | 7.8470E-08 | -8.92902  | 172.1 |   |
| 1210 | -19.27060 | 1.1489E-07 | -8.54778  | 164.7 | Deadwood-Madison Pc=164.7 psi at DW No. 2 |
| 1242 | -19.27060 | 1.2104E-07 | -8.49558  | 163.7 | Deadwood-Madison Pc=163.7 psi at DW No. 4 |
| 1750 | -19.27060 | 2.4031E-07 | -7.80979  | 150.5 |   |
| 2000 | -19.27060 | 3.1388E-07 | -7.54273  | 145.4 |   |
| 2124 | -19.27060 | 3.5401E-07 | -7.42242  | 143.0 |   |
| 2180 | -19.27060 | 3.7292E-07 | -7.37037  | 142.0 |   |
| 3000 | -19.27060 | 7.0623E-07 | -6.73180  | 129.7 |   |
| 3500 | -19.27060 | 9.6126E-07 | -6.42350  | 123.8 |   |
| 4000 | -19.27060 | 1.2555E-06 | -6.15643  | 118.6 |   |
| 4500 | -19.27060 | 1.5890E-06 | -5.92087  | 114.1 |   |
| 5280 | -19.27060 | 2.1876E-06 | -5.60117  | 107.9 |   |
| 6000 | -19.27060 | 2.8249E-06 | -5.34550  | 103.0 |   |
| 6600 | -19.27060 | 3.4181E-06 | -5.15488  | 99.3  |   |
| 6700 | -19.27060 | 3.5225E-06 | -5.12481  | 98.8  |   |
| 6800 | -19.27060 | 3.6284E-06 | -5.09518  | 98.2  |   |
| 6900 | -19.27060 | 3.7359E-06 | -5.06598  | 97.6  |   |
| 7000 | -19.27060 | 3.8450E-06 | -5.03720  | 97.1  |   |
| 7100 | -19.27060 | 3.9557E-06 | -5.00883  | 96.5  |   |
| 7200 | -19.27060 | 4.0679E-06 | -4.98086  | 96.0  |   |
| 7300 | -19.27060 | 4.1817E-06 | -4.95327  | 95.5  |   |
| 7400 | -19.27060 | 4.2970E-06 | -4.92606  | 94.9  |   |

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TABLE A-4 Calculated Pressure Rise vs. Distance (Diffusivity Equation) - Deadwood Formation

|       |           |            |          |      |
|-------|-----------|------------|----------|------|
| 7500  | -19.27060 | 4.4139E-06 | -4.89922 | 94.4 |
| 7600  | -19.27060 | 4.5324E-06 | -4.87273 | 93.9 |
| 7700  | -19.27060 | 4.6525E-06 | -4.84658 | 93.4 |
| 7800  | -19.27060 | 4.7741E-06 | -4.82077 | 92.9 |
| 7900  | -19.27060 | 4.8973E-06 | -4.79530 | 92.4 |
| 8000  | -19.27060 | 5.0221E-06 | -4.77014 | 91.9 |
| 8100  | -19.27060 | 5.1484E-06 | -4.74529 | 91.4 |
| 8200  | -19.27060 | 5.2763E-06 | -4.72075 | 91.0 |
| 8300  | -19.27060 | 5.4058E-06 | -4.69651 | 90.5 |
| 8400  | -19.27060 | 5.5368E-06 | -4.67256 | 90.0 |
| 8500  | -19.27060 | 5.6694E-06 | -4.64889 | 89.6 |
| 9000  | -19.27060 | 6.3561E-06 | -4.53457 | 87.4 |
| 10000 | -19.27060 | 7.8470E-06 | -4.32385 | 83.3 |
| 10560 | -19.27060 | 8.7505E-06 | -4.21488 | 81.2 |
| 11000 | -19.27060 | 9.4949E-06 | -4.13323 | 79.6 |

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June 2011

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Appendix 2.7-L

**Table A-5 Radius of Fluid Displacement Calculation - Minnelusa Formation**

Porosity = 0.21  
 Formation Thickness = 164 ft  
 Injection Rate = 75 gpm

$r$  = radius of fluid displacement     $Q$  = injection volume (ft<sup>3</sup>)

$$r = (Q/((\pi) \cdot h \cdot \text{porosity}))^{0.5}$$

| Elapsed Time (yrs) | Qt (ft <sup>3</sup> ) | r (ft) | r (miles) |
|--------------------|-----------------------|--------|-----------|
| 1                  | 5,270,055             | 221    | 0.04      |
| 5                  | 26,350,275            | 493    | 0.09      |
| 10                 | 52,700,550            | 698    | 0.13      |

**EFFECT OF REGIONAL HYDRAULIC GRADIENT**

ASSUME: Regional gradient = 0.0001 ft/ft (10 ft/mile)

Linear velocity (v<sub>l</sub>):

$v_l = (Kl)/\text{porosity}$  where  $l$  = hydraulic gradient

$K = 4.670$  ft/d

Hyd. Gradient Displacement = (v<sub>l</sub>)\*(time)

| Elapsed Time (yrs) | Injection Displacement Ri (ft) | Hyd. Grad. Displ. Rg (ft) | Total Fluid Displacement Rt (ft) |
|--------------------|--------------------------------|---------------------------|----------------------------------|
| 1                  | 221                            | 0.81                      | 221.51                           |
| 5                  | 493                            | 4.06                      | 497.56                           |
| 10                 | 698                            | 8.12                      | 706.03                           |

NOTE: The additional displacement due to the regional hydraulic gradient is independent of injection rate.

**Table A-6 Radius of Fluid Displacement Calculation - Deadwood Formation**

Porosity = 0.11  
 Formation Thickness = 85 ft  
 Injection Rate = 75 gpm

$r$  = radius of fluid displacement     $Q$  = injection volume (ft<sup>3</sup>)

$$r = (Q/((\pi) * h * \text{porosity}))^{0.5}$$

| Elapsed Time (yrs) | Qt (ft <sup>3</sup> ) | r (ft) | r (miles) |
|--------------------|-----------------------|--------|-----------|
| 1                  | 5,270,055             | 424    | 0.08      |
| 5                  | 26,350,275            | 947    | 0.18      |
| 10                 | 52,700,550            | 1339   | 0.25      |

**EFFECT OF REGIONAL HYDRAULIC GRADIENT**

ASSUME: Regional gradient = 0.0001 ft/ft (10 ft/mile)

Linear velocity (v<sub>l</sub>):

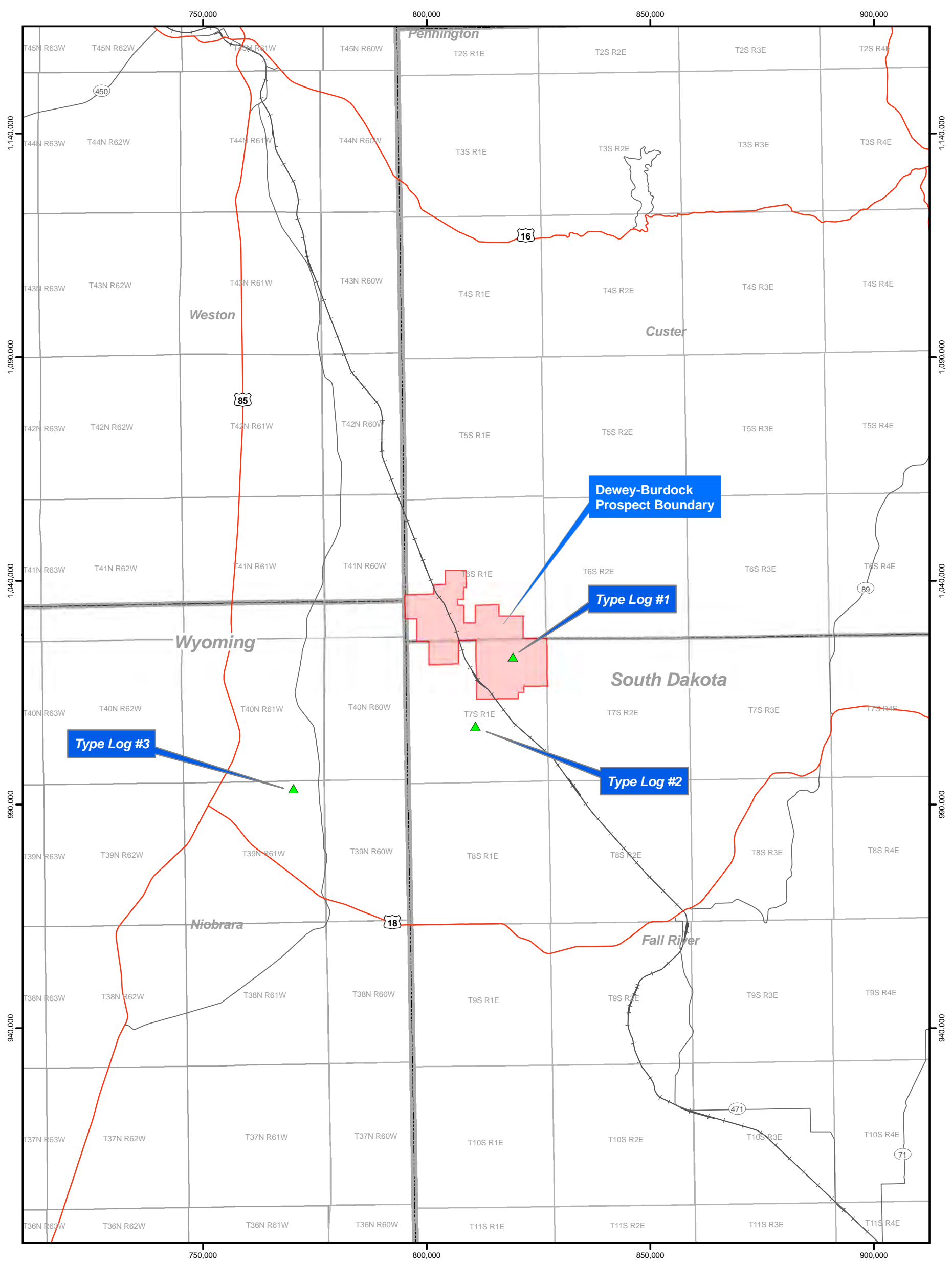
$v_l = (KI)/\text{porosity}$  where  $I$  = hydraulic gradient

$K = 4.670$  ft/d



Hyd. Gradient Displacement = (v<sub>l</sub>)\*(time)

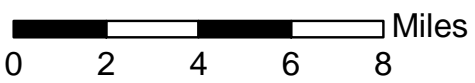
| Elapsed Time (yrs) | Injection Displacement Ri (ft) | Hyd. Grad. Displ. Rg (ft) | Total Fluid Displacement Rt (ft) |
|--------------------|--------------------------------|---------------------------|----------------------------------|
| 1                  | 424                            | 1.55                      | 425.12                           |
| 5                  | 947                            | 7.75                      | 954.88                           |
| 10                 | 1339                           | 15.50                     | 1354.95                          |

NOTE: The additional displacement due to the regional hydraulic gradient is independent of injection rate.



**Legend**

-  Dewey-Burdock Permit Boundary
-  Type Log Location



  
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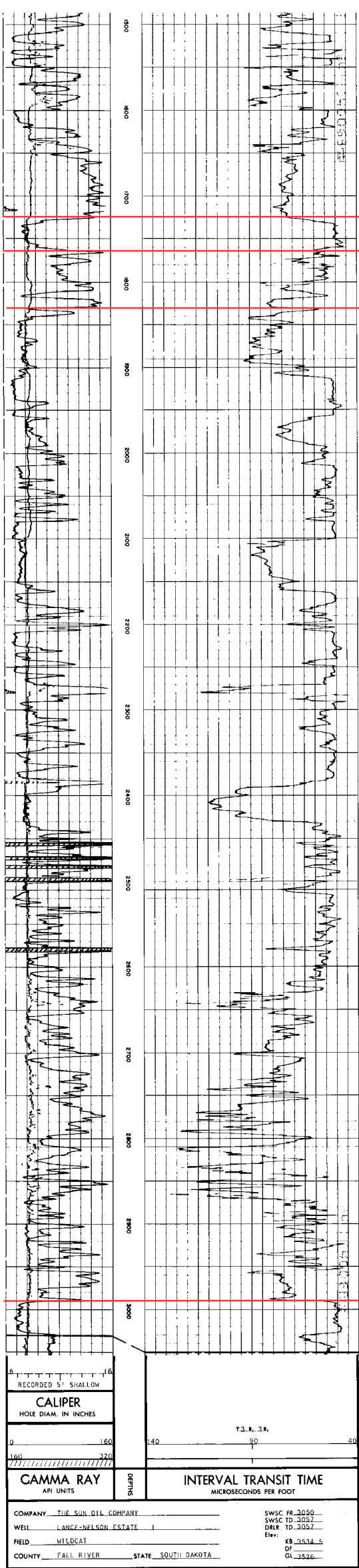
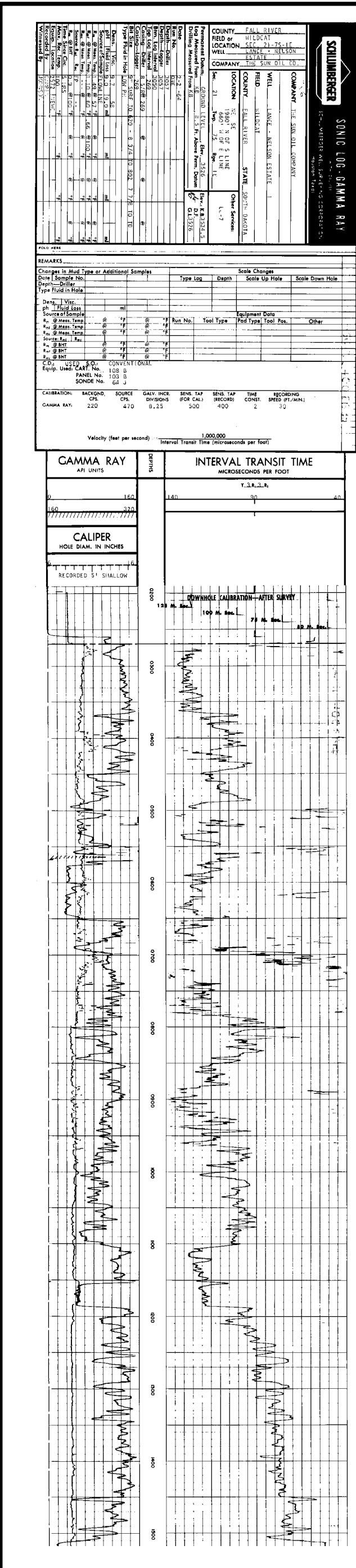
Figure A-1  
Area of Interest  
Showing Location of Type Logs  
2010 Dewey-Burdock Class V Permit

|                              |                     |
|------------------------------|---------------------|
| Scale: 1:250,000             | Date: March 2010    |
| 2010_DB_Class_V_Fig_A-01.mxd | By: JLM Checked: HD |

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1726'  
Minnekahta Limestone  
1765'  
Opeche Shale

1830'  
Minnelusa Formation

2990'  
Madison Formation

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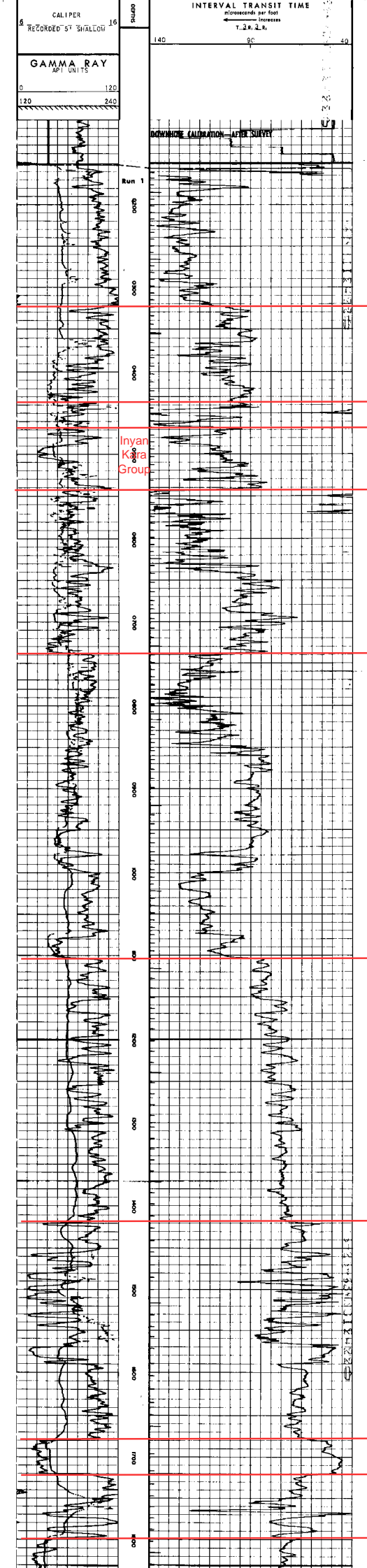
Figure A-3  
Black Hills Area, South Dakota  
Type Log #2  
2010 Dewey-Burdock Class V Permit

|                             |                     |
|-----------------------------|---------------------|
| Scale: NTS                  | Date: March 2010    |
| 2010_DB_Class_V_Fig_A-03.ai | By: JLM Checked: HD |

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|  |  |   |  |
|--|--|---|--|
| <b>SCHUMBERGER</b>   |  | <b>Sonic Log</b>  |  |
| COUNTY: NIJIBBARA<br>TWP: WEST HOLE CREEK<br>LOCATION: SEC. 2, T.10N, R.12E<br>WELL: #1 WEST HOLE CREEK<br>COMPANY: THE CORONADO COMPANY<br>OPERATOR: WEST HOLE CREEK GOVERNMENT A<br>FIELD: WEST HOLE CREEK<br>LOCATION: SEC. 2, T.10N, R.12E<br>COUNTY: NIJIBBARA<br>STATE: WYOMING  |  | COMPANY SURVEY: _____<br>WELL NO.: _____<br>LOCATION OF WELL: _____<br>DATE: _____<br>BY: _____   |  |
| Log Depth: Measured from _____ to _____<br>Log Length: _____<br>Log Weight: _____<br>Log Diameter: _____<br>Log Material: _____<br>Log Condition: _____<br>Log Serial No.: _____<br>Log Manufacturer: _____<br>Log Model: _____<br>Log Year: _____<br>Log Serial No.: _____<br>Log Manufacturer: _____<br>Log Model: _____<br>Log Year: _____<br>Log Serial No.: _____<br>Log Manufacturer: _____<br>Log Model: _____<br>Log Year: _____ |  |   |  |
| REMARKS: VIC No. 3-108 (RUN ONE) 3-108 (RUN TWO) STANDARD CENTRAL PZAR HISTOGRAM RUN ONE<br>VIS No. 3-62 3-62 MUD SAMPLE FROM FLOW LINE--RUN ONE<br>VIC No. 3-103 3-103<br>RUN ONE: GRAB-200-520-A-25-(500)16 LOG SENS. 200 LOG T.C. 2 LOG SPEED 307/MIN<br>RUN TWO: GRAB-200-520-B-25-(500)16 LOG SENS. 200 LOG T.C. 2 LOG SPEED 187/MIN<br>Velocity (feet per second) Interval Transit Time (microseconds per foot)                    |  |   |  |
| RUN ONE: RHF: .437 - .95*F<br>RUN TWO: RHF: 1.1 - 100*F  |  | RUN ONE: TOTAL FOOTAGE LOGGED-2788'<br>TOTAL TRAVEL TIME: 225.8 MILLISEC.<br>TOTAL FOOTAGE LOGGED-2468'<br>TOTAL TRAVEL TIME: 284 MILLISEC. |  |



322'  
Fall River Formation

436'  
Fuson Member

468'  
Lakota Formation

543'  
Morrison Formation

738'  
Sundance Formation

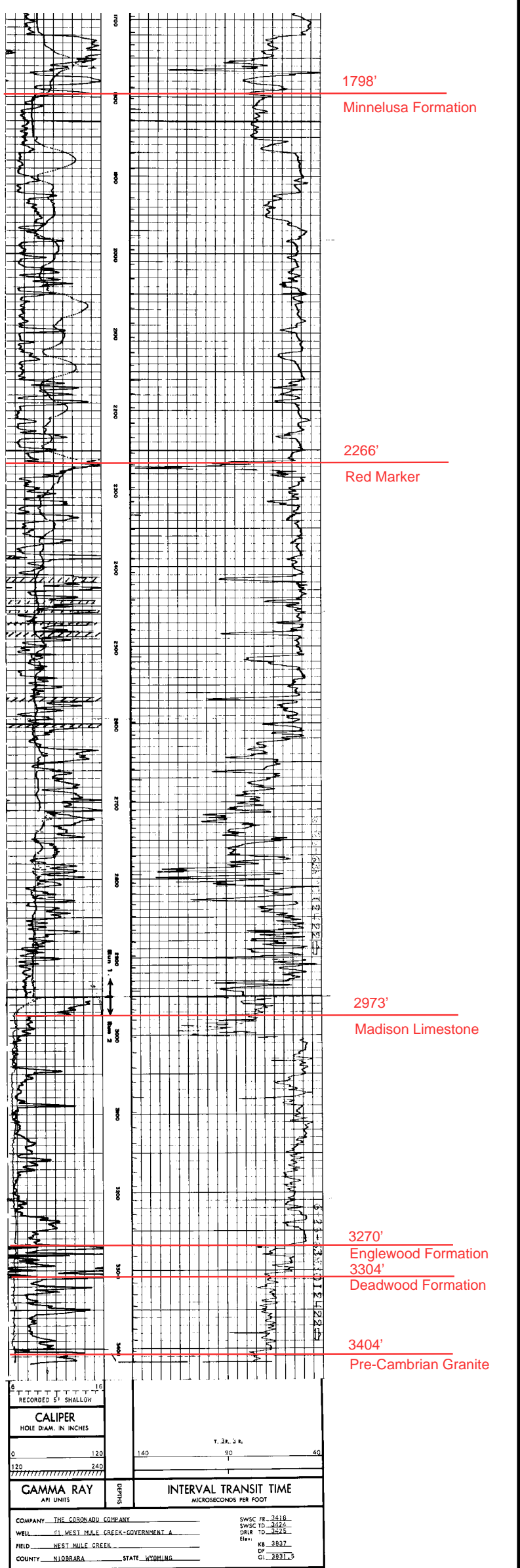
1103'  
Spearfish Formation

1418'  
Goose Egg Formation

1678'  
Minnekahta Limestone

1721'  
Opeche Shale

1798'  
Minnelusa Formation



1798'  
Minnelusa Formation

2266'  
Red Marker

2973'  
Madison Limestone

3270'  
Englewood Formation

3304'  
Deadwood Formation

3404'  
Pre-Cambrian Granite

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Figure A-4  
Eastern Powder River Basin  
Type Log #3  
2010 Dewey-Burdock Class V Permit

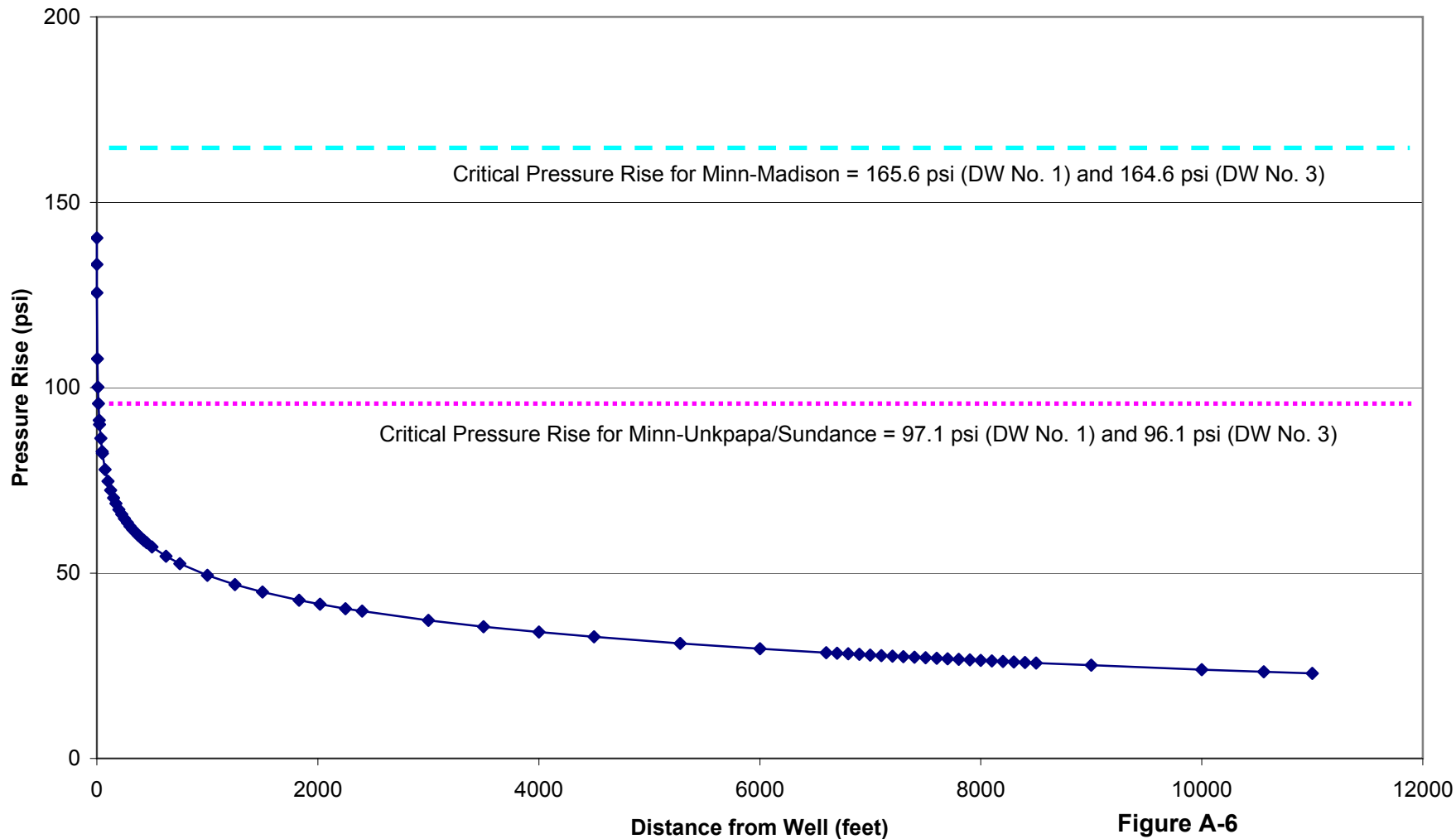
|                             |                     |
|-----------------------------|---------------------|
| Scale: NTS                  | Date: March 2010    |
| 2010_DB_Class_V_Fig_A-04.ai | By: JLM Checked: HD |

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**10-Year Calculated Pressure Rise in Minnelusa Injection Target**  
**Q= 75 gpm, Injection Duration = 10 years**



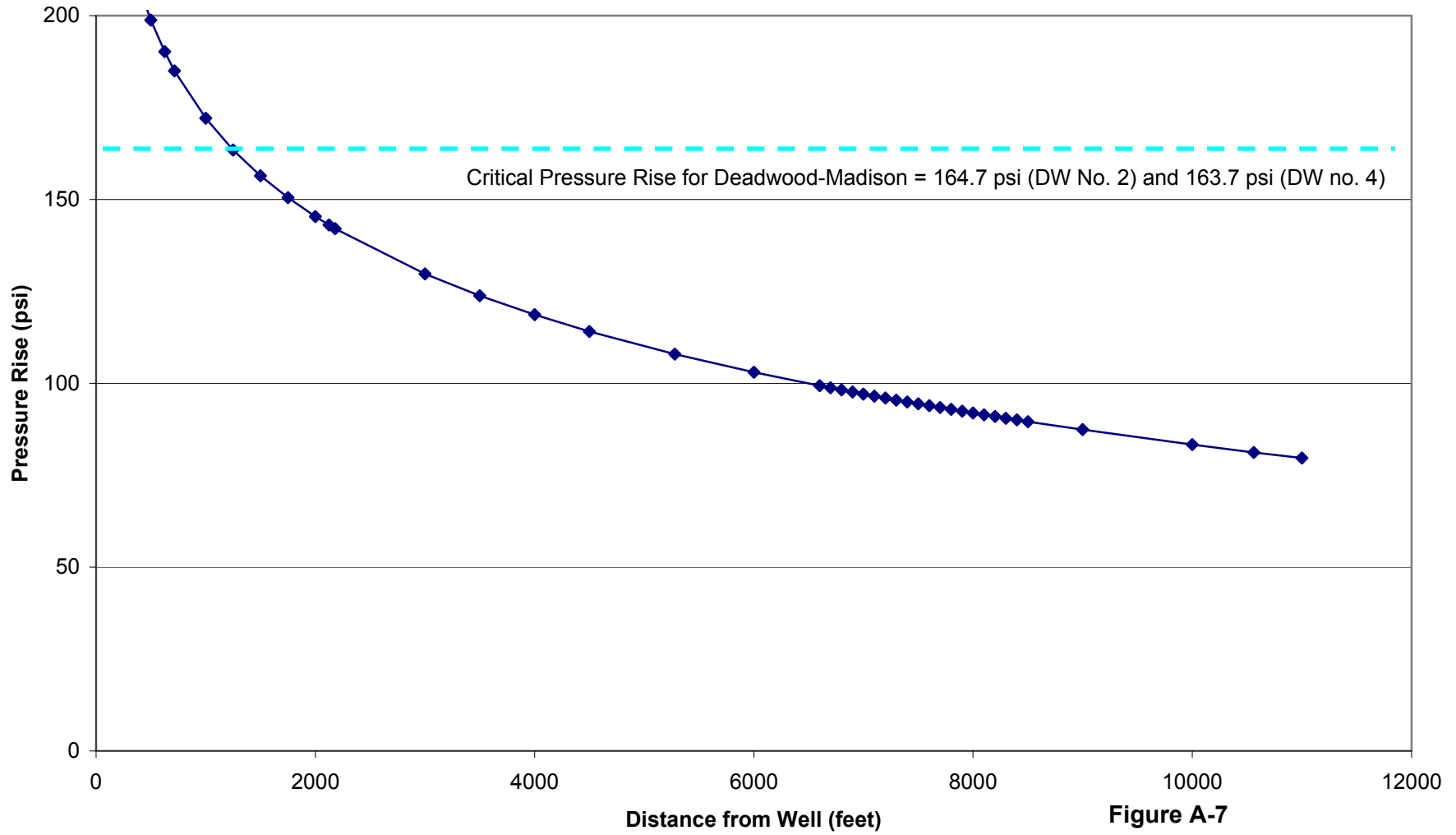
Dewey-Burdock TR  
June 2011

2.7-L-36

Appendix 2.7-L

Figure A-6

**10-Year Calculated Pressure Rise in Deadwood Injection Target**  
**Q= 75 gpm, Injection Duration = 10 years**



Dewey-Burdock TR  
June 2011

2.7-L-37

Appendix 2.7-L

**Figure A-7**

## **2.B MAPS OF WELLS IN AREA AND AREA OF REVIEW**

*Submit a topographic map, extending one mile beyond the property boundaries, showing the injection well(s) or project area for which a permit is sought and the applicable area of review. The map must show all intake and discharge structures and all hazardous waste, treatment, storage, or disposal facilities. If the application is for an area permit, the map should show the distribution manifold (if applicable) applying injection fluid to all wells in the area, including all system monitoring points. Within the area of review, the map must show the following:*

*The number, or name, and location of all producing well, injection well, abandoned well, dry holes, surface bodies of water, springs, mines (surface and subsurface), quarries, and other pertinent surface features, including residences and roads, and faults, if known or suspected. In addition, the map must identify those well, springs, other surface water bodies, and drinking water wells located within one-quarter mile of the facility property boundary. Only information of public record is required to be included on this map.*

### **RESPONSE**

Maps based on available public records have been prepared and submitted in this Response as summaries of the required data.

#### **Topographic Map**

A copy of the USGS Topographic map available with the outline of the Dewey-Burdock Project boundary superimposed on the map is included as Figure B-1. In addition, the map shows the location of all known surface bodies of water, springs, mines, quarries, residencies and roads.

#### **Artificial Penetrations**

There are two artificial penetrations identified in the areas of review surrounding Site 1 and one in the areas of review surrounding Site 2. Figures B-2 and B-2a show the artificial penetrations within the AORs for DW Nos. 1 through 4 for the Minnelusa and the Deadwood, respectively.

Figure B-2b, a map generated using regional data provided by the state of South Dakota, shows the Proposed Class V permit area, the location of the required AORs for four of the proposed Dewey-Burdock Disposal Wells, and the locations of surrounding oil and gas wells. Figure B-2c presents the location of all known water wells within the proposed Class V permit area.

Table C-1 is a tabulation of the known water wells located within the Class V permit area. The deepest formation penetrated by any of these wells is the Unkpapa/Sundance. Due to the absence of wells within the Class V permit area that penetrate the injection zones, there is little potential for causing any endangerment to a USDW.

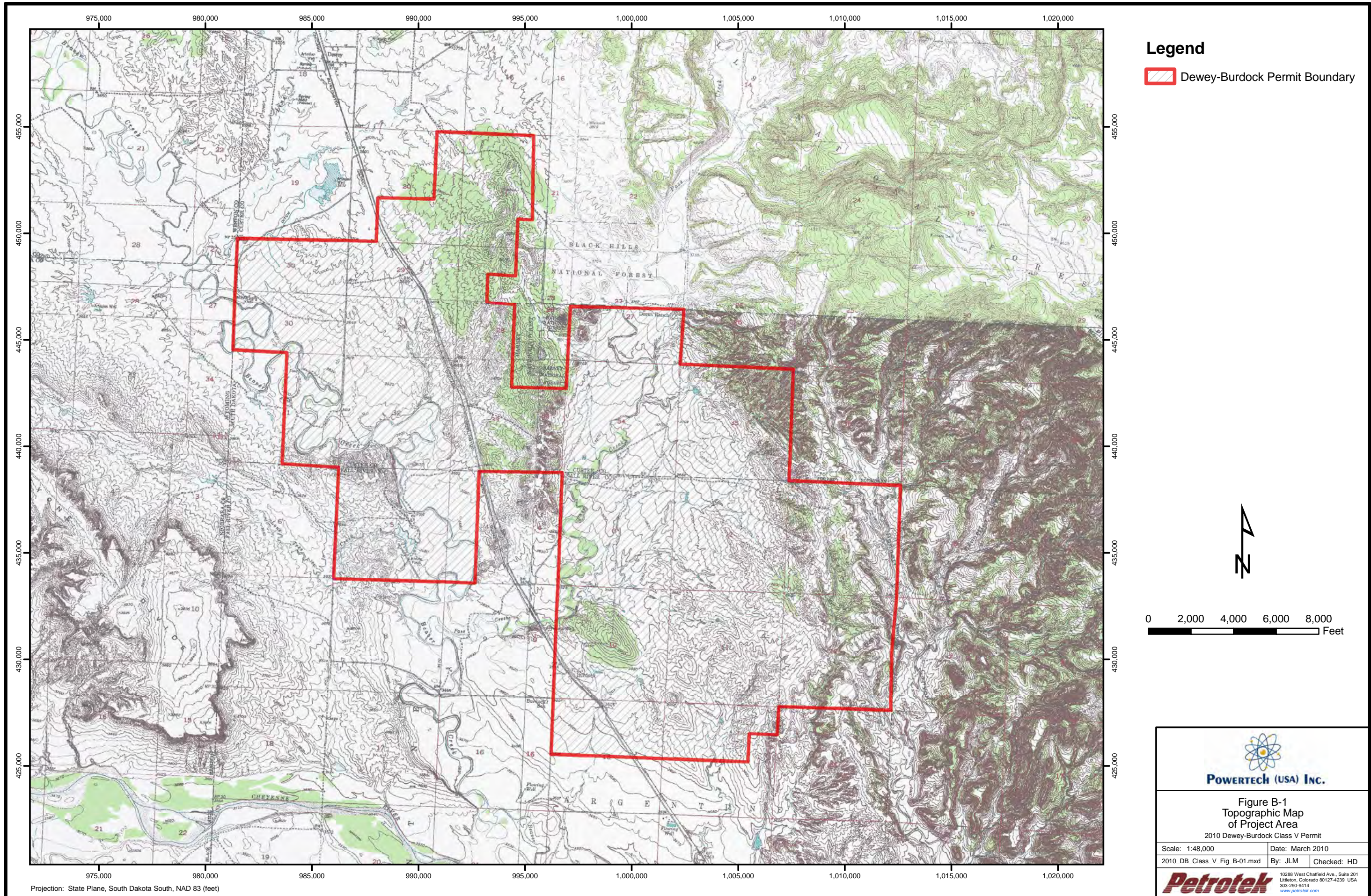
Table C-2 is a tabulation of the three oil and gas wells permitted within the Dewey-Burdock Project area. The plugging records for these well are included as Appendix B. According to the records obtained from DENR, each of the wells is plugged to a sufficient depth so as not to allow transmission of fluids from the targeted injection zones to overlying USDWs. Note that none of these wells are located within the proposed Class V permit area. As such, they will not be encompassed in any prospective AORs of proposed Dewey-Burdock Disposal Wells.

### **Property Ownership and Public Notice**


Figure B-3 shows the surface property owners in the Dewey-Burdock Project area and Figure B-4 shows the mineral ownership within the Dewey-Burdock Project boundary.

For the purpose of public notice, newspaper service is available from several publishers in the area including the closest paper to the proposed facility, the Edgemont Herald Tribune.





**Legend**

 Dewey-Burdock Permit Boundary



0 2,000 4,000 6,000 8,000  
Feet



**Figure B-1  
Topographic Map  
of Project Area**

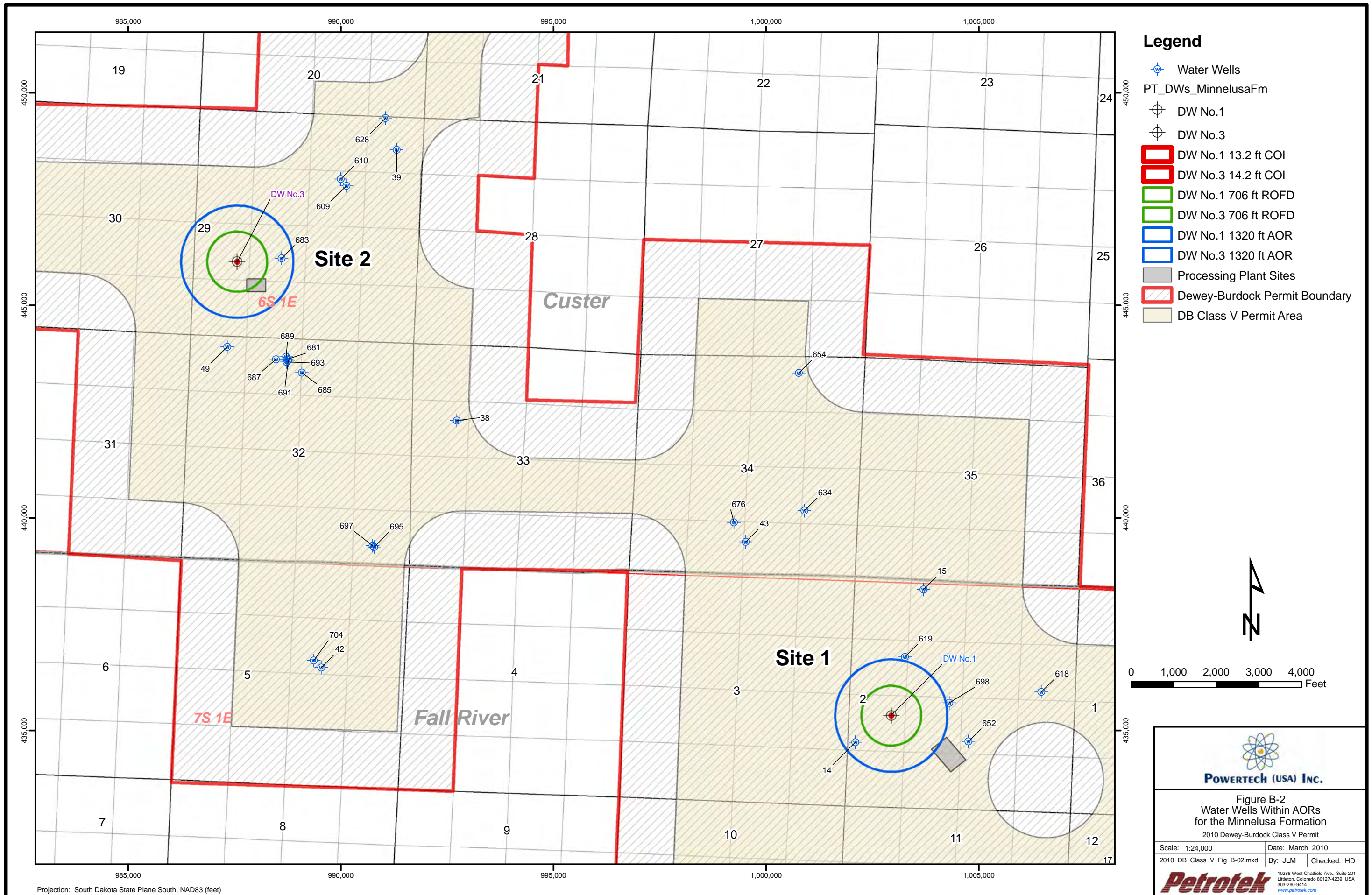
2010 Dewey-Burdock Class V Permit

|                              |                     |
|------------------------------|---------------------|
| Scale: 1:48,000              | Date: March 2010    |
| 2010_DB_Class_V_Fig_B-01.mxd | By: JLM Checked: HD |

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Projection: State Plane, South Dakota South, NAD 83 (feet)





- Legend**
- Water Wells
  - PT\_DWs\_MinnelusaFm
  - DW No.1
  - DW No.3
  - DW No.1 13.2 ft COI
  - DW No.3 14.2 ft COI
  - DW No.1 706 ft ROFD
  - DW No.3 706 ft ROFD
  - DW No.1 1320 ft AOR
  - DW No.3 1320 ft AOR
  - Processing Plant Sites
  - Dewey-Burdock Permit Boundary
  - DB Class V Permit Area

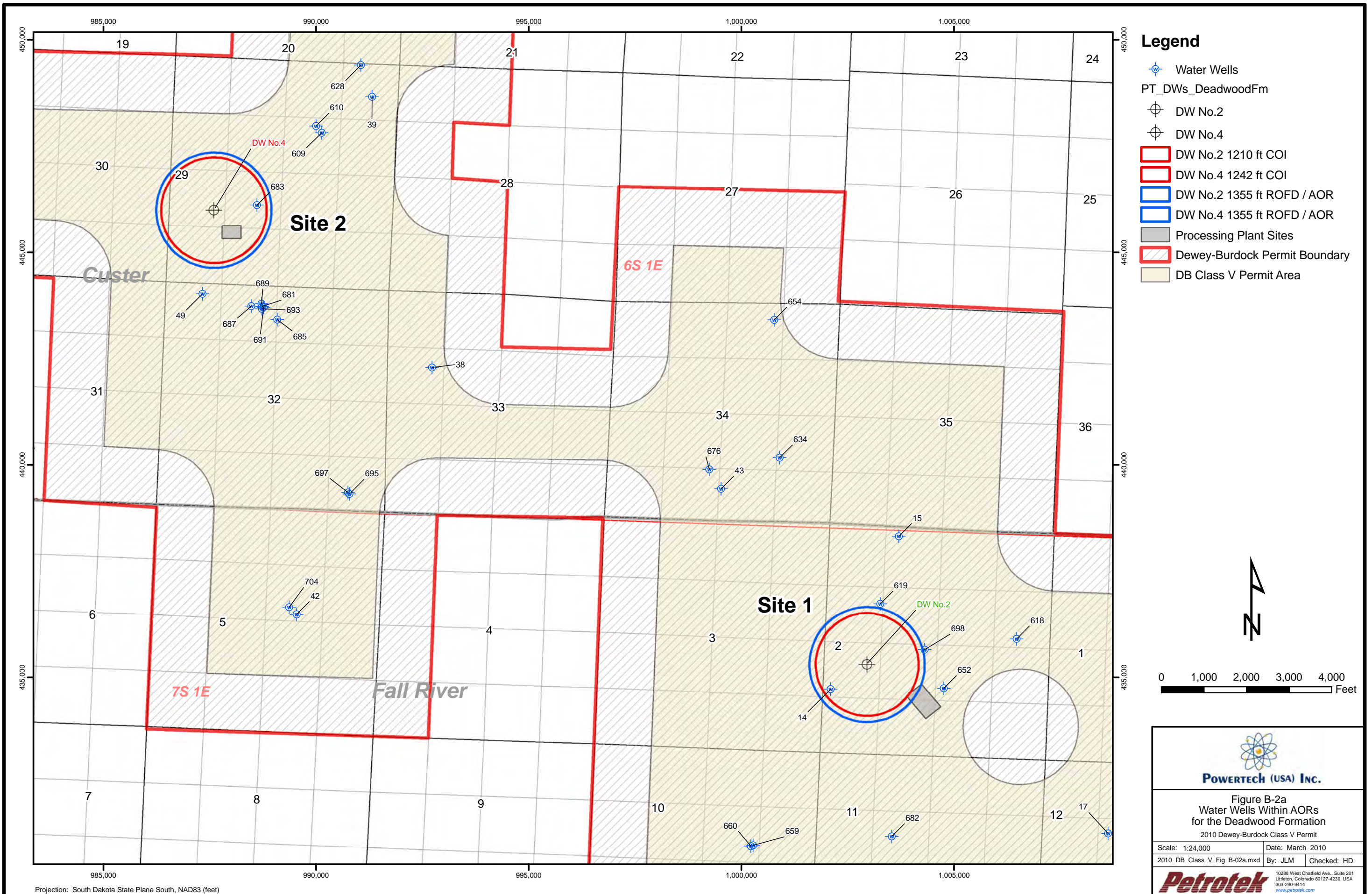
**PowerTech (USA) Inc.**

Figure B-2  
Water Wells Within AORs  
for the Minnelusa Formation  
2010 Dewey-Burdock Class V Permit

|                              |                        |
|------------------------------|------------------------|
| Scale: 1:24,000              | Date: March 2010       |
| 2010_DB_Class_V_Fig_B-02.mxd | By: JLM    Checked: HD |

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303-290-9414  
www.petrotek.com





Projection: South Dakota State Plane South, NAD83 (feet)

**Legend**

- Water Wells
- PT\_DWs\_DeadwoodFm
- DW No.2
- DW No.4
- DW No.2 1210 ft COI
- DW No.4 1242 ft COI
- DW No.2 1355 ft ROFD / AOR
- DW No.4 1355 ft ROFD / AOR
- Processing Plant Sites
- Dewey-Burdock Permit Boundary
- DB Class V Permit Area

0 1,000 2,000 3,000 4,000 Feet

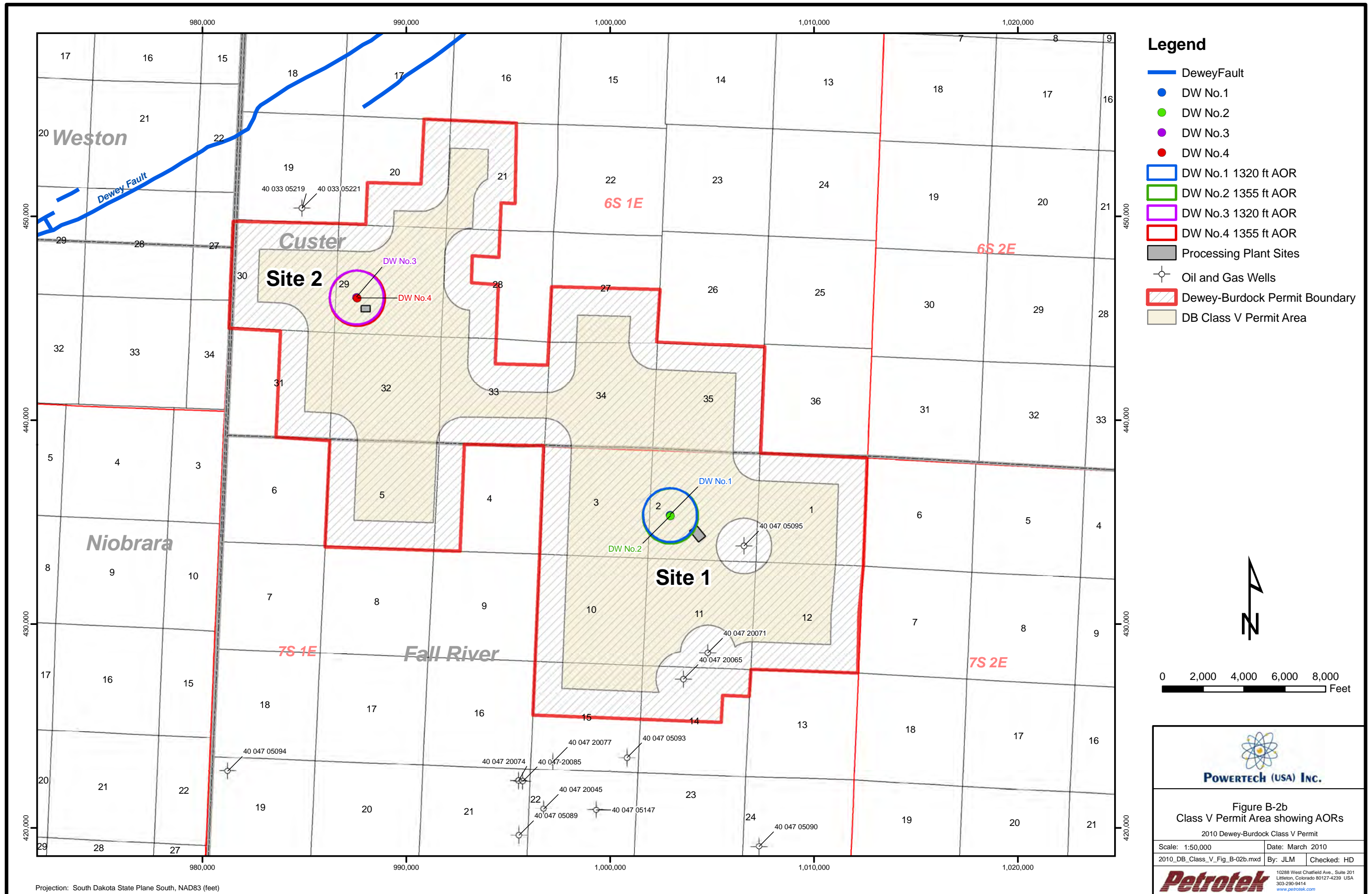
**POWERTECH (USA) INC.**

Figure B-2a  
Water Wells Within AORs  
for the Deadwood Formation  
2010 Dewey-Burdock Class V Permit

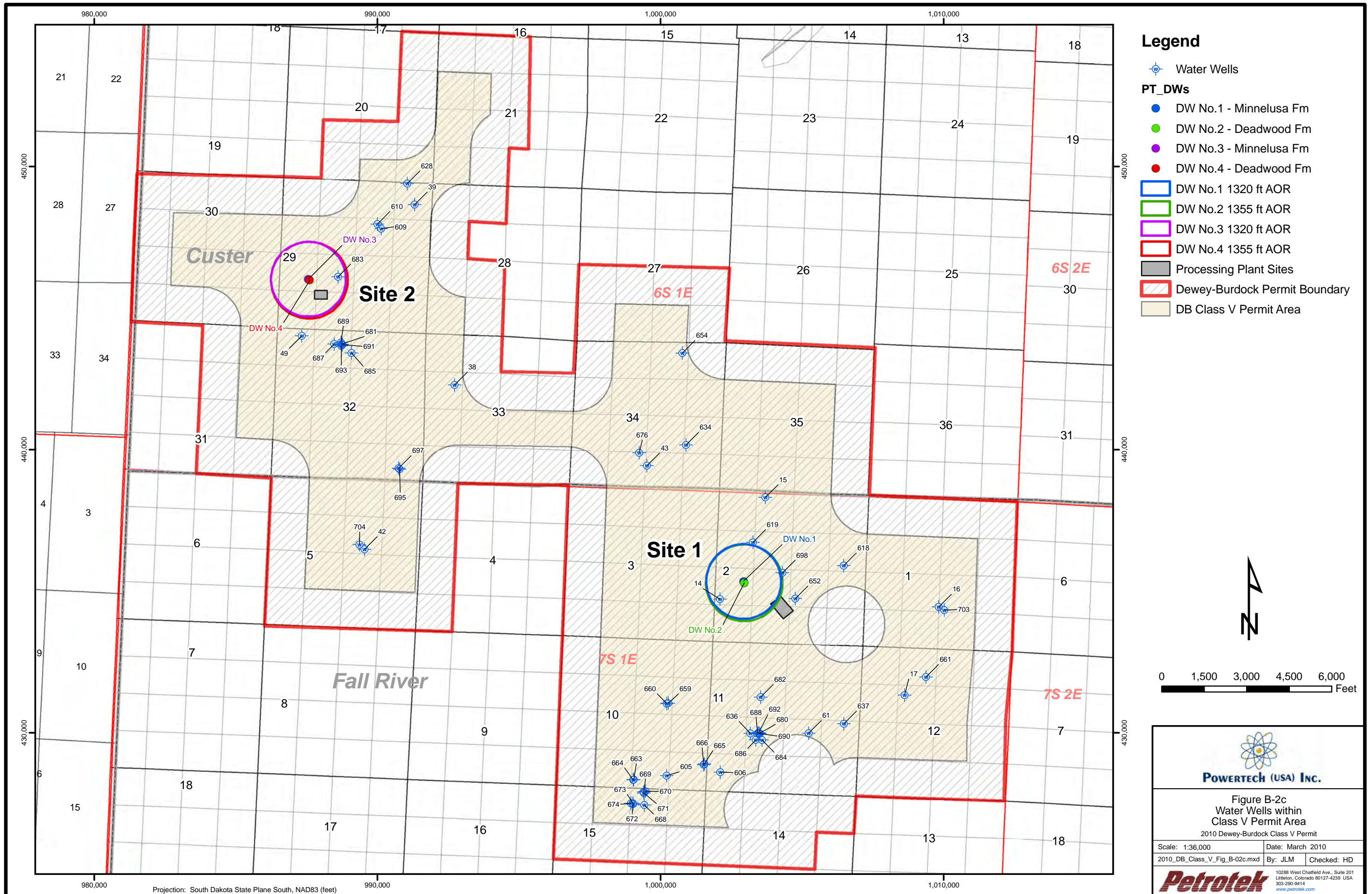
|                               |                     |
|-------------------------------|---------------------|
| Scale: 1:24,000               | Date: March 2010    |
| 2010_DB_Class_V_Fig_B-02a.mxd | By: JLM Checked: HD |

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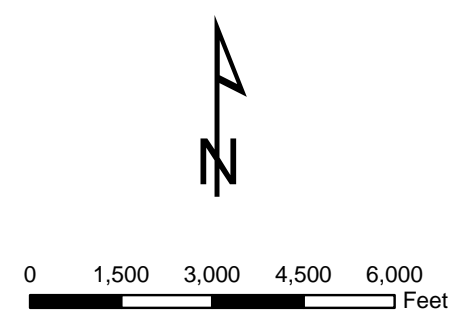








- Legend**
- Water Wells
  - PT\_DWs**
  - DW No.1 - Minnelusa Fm
  - DW No.2 - Deadwood Fm
  - DW No.3 - Minnelusa Fm
  - DW No.4 - Deadwood Fm
  - DW No.1 1320 ft AOR
  - DW No.2 1355 ft AOR
  - DW No.3 1320 ft AOR
  - DW No.4 1355 ft AOR
  - Processing Plant Sites
  - Dewey-Burdock Permit Boundary
  - DB Class V Permit Area



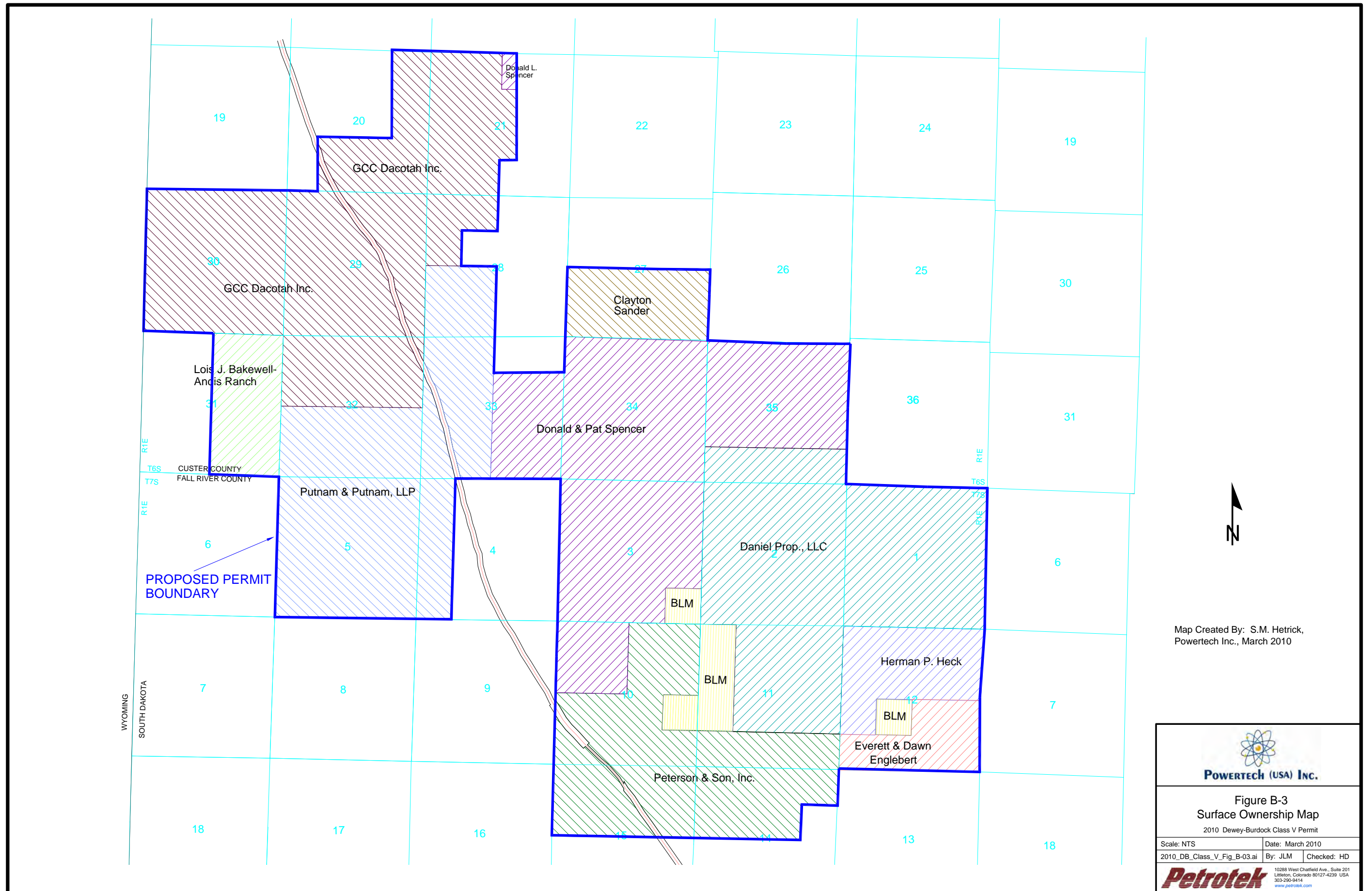
**POWERTEK (USA) INC.**

Figure B-2c  
Water Wells within  
Class V Permit Area  
2010 Dewey-Burdock Class V Permit



|                               |                        |
|-------------------------------|------------------------|
| Scale: 1:36,000               | Date: March 2010       |
| 2010_DB_Class_V_Fig_B-02c.mxd | By: JLM    Checked: HD |

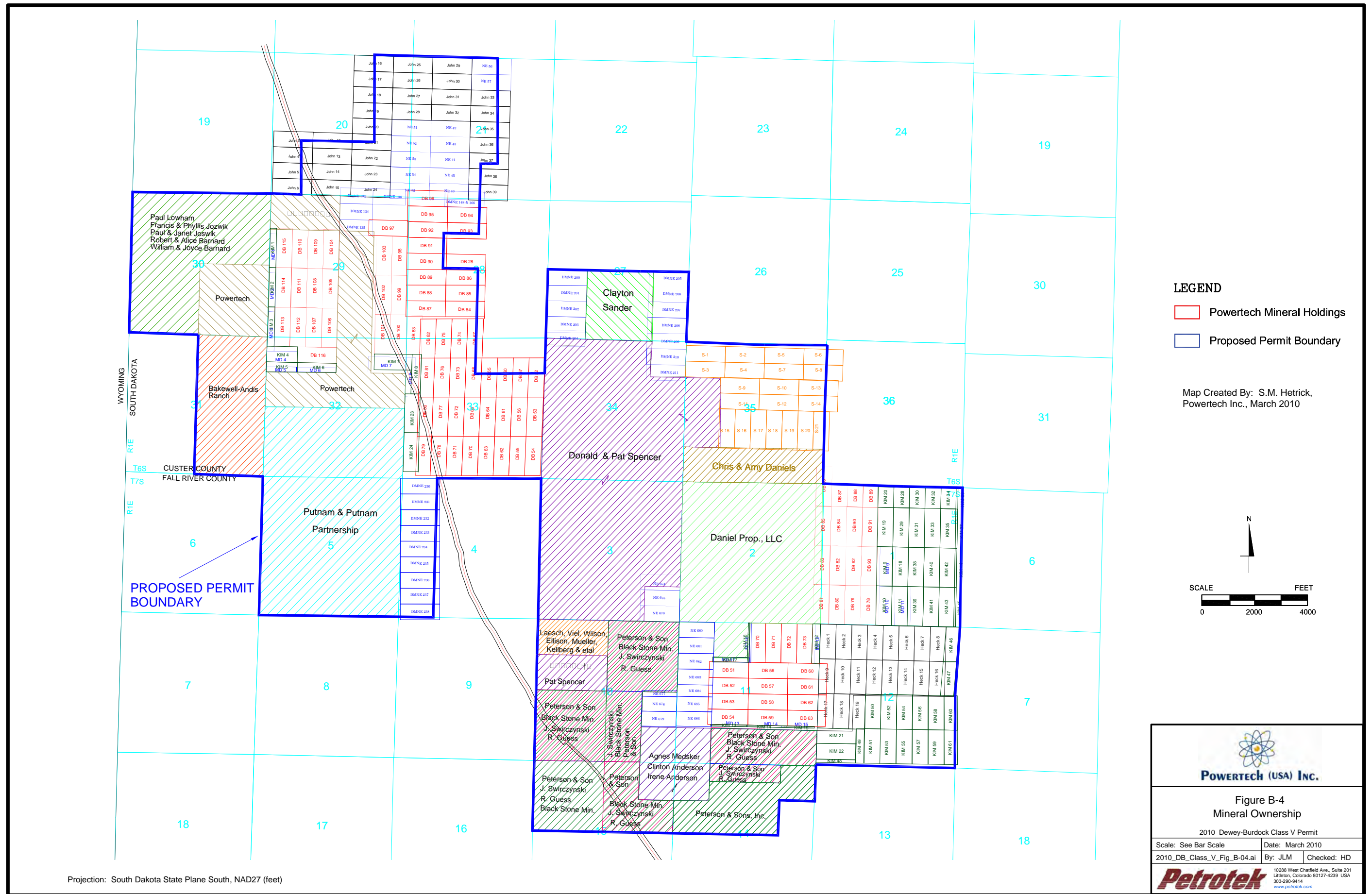
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Map Created By: S.M. Hetrick,  
Powertech Inc., March 2010

|  |                  |             |
|--|------------------|-------------|
| <br><b>POWERTECH (USA) INC.</b>                                 |                  |             |
| <b>Figure B-3</b><br><b>Surface Ownership Map</b><br>2010 Dewey-Burdock Class V Permit   |                  |             |
| Scale: NTS   | Date: March 2010 |             |
| 2010_DB_Class_V_Fig_B-03.ai  | By: JLM          | Checked: HD |
|   |                  |             |
| 10288 West Chatfield Ave., Suite 201<br>Littleton, Colorado 80127-4239 USA<br>303-290-9414<br><a href="http://www.petrotek.com">www.petrotek.com</a> |                  |             |



## 2.C CORRECTIVE ACTION PLAN AND WELL DATA

*Submit a tabulation of data reasonably available from public records or otherwise known to the applicant on all wells within the area of review, including those on the map required in Attachment B, which penetrate the proposed injection zone. Such data shall include the following:*

*A description of each well's type, construction, date drilled, location, depth, record of plugging and/or completion, and any additional information the Director may require. In the case of a new injection well, include the corrective action proposed to be taken by the applicant under 40 CFR 144.55.*

### RESPONSE

#### Corrective Action

A corrective action plan is not required for any of the artificial penetrations within the AORs of the proposed Dewey-Burdock wells or the Class V permit area because there are no artificial penetrations to the injection zone within the Class V permit area. If a corrective action plan for any neighboring well becomes necessary in the future, it will be developed according to appropriate regulatory standards and guidelines.

The corrective action plan which would be proposed by Powertech should the potential for fluid migration to occur through the confining layer develop via any future well likely would include the following:

1. The impacted Dewey-Burdock Project Disposal Well will be shut-in.
2. The USEPA, Region 8 UIC Section and the SD DENR will be notified.
3. Following well shut-in, liquid 11e2 waste will be shipped to alternative permitted facilities for off-site treatment and/or disposal as necessary.
4. A contingency plan will be prepared as follows:
  - a. Locate well and identify present operator or owner, if any.
  - b. Identify mode of failure.
  - c. Prepare remedial plan outlining course of action.
  - d. The remedial plan will be submitted to the USEPA, Region 8 and SD DENR for approval.
  - e. Upon authorization, the remedial plan will be implemented.

#### Water Wells within AORs

Table C-1 is a tabulation of the known artificial penetrations (water wells) located within the Class V permit area. The deepest formation penetrated by any of these wells is the Unkpapa/Sundance. Due to the absence of wells within the Class V permit area that penetrate either of the targeted injection zones, there is no potential from artificial penetrations for causing any endangerment to a USDW.

### **Area of Review Oil and Gas Well Data**

Table C-2 is a tabulation of the three oil and gas wells permitted within the Dewey-Burdock Project area that are outside the assigned AORs. The plugging records for these wells are included as Appendix B. Plugging records obtained from DENR indicate that each of the wells is plugged to a sufficient depth so as not to allow transmission of fluids from the targeted injection zones to overlying USDWs. Note that none of these wells are located within the proposed Class V permit area. As such, they will not be encompassed in any prospective future AORs of proposed additional Dewey-Burdock Disposal Wells.

**TABLE C-1 Known Water Wells Within Class V Permit Area**

| Well ID | Well Depth (ft) | Formation        | Abandoned | Depth to Water (ft) |
|---------|-----------------|------------------|-----------|---------------------|
| 605     | Unknown         | Inyan Kara       | no        | Unknown             |
| 606     | Unknown         | Lakota           | yes       | 0                   |
| 42      | 600             | Lakota           | no        | -10                 |
| 61      | 525             | Lakota           | unknown   | Unknown             |
| 16      | 330             | Lakota           | no        | 158                 |
| 618     | Unknown         | Unknown          | no        | Unknown             |
| 15      | 495             | Lakota           | yes       | 0                   |
| 634     | Unknown         | Unknown          | yes       | Unknown             |
| 43      | 350             | Lakota           | yes       | Unknown             |
| 14      | 470             | Lakota           | unknown   | -1                  |
| 636     | Unknown         | Unknown          | yes       | Unknown             |
| 637     | Unknown         | Unknown          | no        | Unknown             |
| 17      | 156             | Fall River       | no        | Unknown             |
| 39      | Unknown         | Unknown          | unknown   | Unknown             |
| 652     | 280             | Inyan Kara       | yes       | Unknown             |
| 654     | Unknown         | Inyan Kara       | yes       | Unknown             |
| 659     | Unknown         | Fall River       | yes       | Unknown             |
| 660     | Unknown         | Lakota           | yes       | Unknown             |
| 661     | Unknown         | Lakota           | unknown   | Unknown             |
| 663     | 550             | Lakota           | unknown   | Unknown             |
| 664     | 360             | Fall River       | unknown   | Unknown             |
| 665     | 252             | Fall River       | unknown   | Unknown             |
| 666     | 441             | Lakota           | unknown   | Unknown             |
| 669     | 550             | Lakota           | unknown   | Unknown             |
| 670     | 395             | Fuson            | unknown   | Unknown             |
| 671     | 350             | Fall River       | unknown   | Unknown             |
| 672     | 376             | Fall River       | unknown   | Unknown             |
| 673     | 440             | Fuson            | unknown   | Unknown             |
| 674     | 570             | Lakota           | unknown   | Unknown             |
| 676     | 23              | Alluvial         | no        | Unknown             |
| 683     | 650             | Fall River       | no        | 5                   |
| 687     | 608             | Fall River       | no        | Unknown             |
| 685     | 595             | Fall River       | no        | Unknown             |
| 682     | 460             | Lakota           | no        | Unknown             |
| 686     | 428             | Lakota           | no        | Unknown             |
| 684     | 423             | Lakota           | no        | Unknown             |
| 690     | 623             | Unkpapa/Sundance | no        | -29                 |
| 692     | 327             | Lakota           | no        | Unknown             |
| 38      | 494             | Lakota           | no        | -14                 |
| 609     | 1000            | Lakota           | no        | 7                   |
| 610     | Unknown         | Fall River       | no        | Unknown             |
| 619     | 280             | Lakota           | no        | 19                  |
| 628     | Unknown         | Inyan Kara       | no        | Unknown             |
| 668     | 574             | Inyan Kara       | no        | Unknown             |
| 698     | 205             | Fall River       | no        | Unknown             |
| 704     | 955             | Unkpapa/Sundance | no        | Unknown             |
| 703     | 525             | Unkpapa/Sundance | no        | Unknown             |
| 695     | 508             | Fall River       | no        | Unknown             |

**TABLE C-1 Known Water Wells Within Class V Permit Area**

| <b>Well ID</b> | <b>Well Depth (ft)</b> | <b>Formation</b> | <b>Abandoned</b> | <b>Depth to Water (ft)</b> |
|----------------|------------------------|------------------|------------------|----------------------------|
| 697            | 682                    | Lakota           | no               | Unknown                    |
| 691            | 505                    | Fall River       | no               | Unknown                    |
| 693            | 910                    | Unkpapa/Sundance | no               | -138                       |
| 689            | 730                    | Lakota           | no               | -59                        |
| 681            | 600                    | Fall River       | no               | -13                        |
| 49             | 600                    | Fall River       | no               | Unknown                    |
| 688            | 255                    | Fall River       | no               | 37                         |
| 680            | 436                    | Lakota           | no               | 39                         |

Source: 2009 Powertech Dewey-Burdock NRC Application

TABLE C-2 Oil and Gas Wells Within Project Area

| Well API     | Name                   | Well Depth (ft) | Formation | Well Status           |
|--------------|------------------------|-----------------|-----------|-----------------------|
| 40-047-05095 | Earl Darrow #1         | 2,450           | Minnelusa | Plugged and Abandoned |
| 40-047-20071 | #34-11 Peterson        | 2,250           | Minnelusa | Plugged and Abandoned |
| 40-047-20065 | Lenore Peterson #21-14 | 2,266           | Minnelusa | Plugged back to 850'  |



## 2.D MAPS AND CROSS SECTIONS OF USDWs

*Submit maps and cross sections indicating the vertical limits of all underground sources of drinking water within the area of review (both vertical and lateral limits for Class I), their position relative to the injection formation and the direction of water movement, where known, in every underground source of drinking water which may be affected by the proposed injection activities.*

### RESPONSE

The major bedrock aquifers in the Black Hills area include the Deadwood, Madison, Minnelusa, Minnekahta, and Inyan Kara (Carter et al, 2003). These aquifers are regionally extensive in areas surrounding the Black Hills as shown on Figure D-1 (Driscoll et al., 2002). A regional east-west geologic cross section across the Black Hills Uplift is shown on Figure D-2. The location of the cross section A-A' is indicated on Figure D-1. Ground-water flow in the regional aquifer system in the Paleozoic aquifer units (i.e., Deadwood, Madison, Minnelusa, and Minnekahta Formations) is generally interpreted to be radially outward from the outcrops surrounding the Black Hills (Figure D-3). Groundwater recharge from the Black Hills area comingles with groundwater in the Powder River Basin to the west and then migrates northeastward into the Williston Basin where it eventually discharges at lower elevations to the land surface in eastern North Dakota and along the outcrop of the Canadian Shield in Canada.

Only two of these major aquifers, the Madison and Inyan Kara, are considered to be USDWs within the AORs of the Dewey-Burdock Disposal Wells. As discussed below, the Deadwood, Minnelusa, and Minnekahta do not supply water wells in the Dewey-Burdock area and are not considered to be USDWs locally. Further, due to local total dissolved solids (TDS) concentrations in excess of 10,000 mg/l, (shown Table D-1 from the USGS Produced Waters Database [<http://energy.cr.usgs.gov/prov/prodwat/data2.htm>]), the Minnelusa is not a USDW.

Minor aquifers in the area include the Sundance formation (Driscoll et al., 2002). While some authors differentiate geologically between the Sundance and overlying Unkpapa Formation, they are thought to be hydrogeologically connected and are referred to as the Unkpapa/Sundance in this document. Further, the Unkpapa/Sundance is considered to be the lower-most USDW above the Madison below the Dewey-Burdock Project area.

#### Deadwood Formation

The Cambrian-age Deadwood Formation consists of massive to thinly-bedded, brown to light-gray sandstone; greenish glauconitic shale; dolomite; and flat-pebble limestone conglomerate. Sandstone with conglomerate occurs locally at the base of the formation. The Deadwood ranges in thickness from 0 to 500 feet (Carter et al., 2003) in the area. Generally, groundwater flow in the Cambrian-Ordovician aquifer system is from the high-altitude recharge areas on the top of the Black Hills radially outward (Figure D-4). Regionally the Deadwood is confined by the Precambrian basement (Williamson and Carter, 2001). It overlies the Precambrian basement and granite wash (where present) and outcrops approximately 20 miles to the northeast of the Dewey-Burdock Project (Figure D-1). As stated previously, the Deadwood is not considered to be a local USDW. Based on available data, there are no known water wells supplied by the Deadwood Formation in the Dewey-Burdock Project area. There are no water quality data available in the area, but it is suspected that water quality declines with depth and distance down-gradient from the recharge at the outcrop. As a result, it is likely that the Deadwood contains dissolved solids in excess of 10,000 mg/l below Sites 1 and 2 and will not meet the USEPA criteria for a USDW. An isopach map of the Deadwood is included as Figure D-5.

### Madison Formation

The Mississippian Madison aquifer is contained within the limestones, siltstones, sandstones, and dolomite of the Madison Limestone or Group. Generally, water in the Madison is confined except in outcrop areas and can frequently demonstrate artesian conditions. Groundwater flow in this aquifer system generally is from the recharge areas radially outward from the Black Hills (Figure D-6). Water in the Madison is typically fresh only near the recharge areas, becoming slightly saline to saline as it moves down-gradient (Figure D-7). In the deeper parts of the Williston Basin, the water is a brine with dissolved solids concentrations greater than 300,000 mg/L (Driscoll et al., 2002). Local water quality for the Madison is summarized by analysis of the Edgemont city wells and is presented in Table D-1. Structure contour and isopach maps of the Madison are included as Figures D-8 and D-9, respectively. A potentiometric surface map of the Madison Formation is presented as Figure D-10.

### Minnelusa Formation

The Pennsylvanian- and Permian-age Minnelusa Formation consists of yellow to red, cross-stratified sandstone, limestone, dolomite, and shale. The Minnelusa Aquifer occurs primarily in sandstone and anhydrite beds in the upper part of the formation (Williamson and Carter, 2001). Water in this aquifer moves from recharge areas radially outward from the Black Hills and to the northeast to discharge areas in eastern South Dakota (Figure D-6). It is confined above by the Opeche Shale and below by layers of lower permeability in the Minnelusa Formation.

The Minnelusa is referred to as an aquifer but is an oil and gas producer in the Dewey-Burdock area. Table D-2 and Figure D-11 present local water quality data from the USGS Produced Waters Database for the Minnelusa Formation that shows TDS concentrations in excess of 10,000 mg/l in the Dewey-Burdock area. In addition, this formation does not supply water to any local water wells. As such, it is not considered to be a USDW in the Dewey-Burdock area. Structure contour and isopach maps of the Minnelusa are included as Figures D-12 and D-13, respectively. A potentiometric surface map of the Minnelusa Formation is presented as Figure D-14.

It has been postulated that in the vicinity of the Black Hills, there may be communication between the Madison and Minnelusa Formations and even communication from the Minnelusa to the surface via breccia pipes. However, this communication is thought to occur near the outcrop in areas where these formations are near surface. These areas are located well to the north and east of the Project area and up-gradient in the system. Evidence of regional isolation is the contrast between water quality in the Madison and Minnelusa. There is no evidence to suggest that there is communication between these formations locally.

### Minnekahta Formation

The Permian-age Minnekahta Limestone is a thin to medium-bedded, fine-grained, purple to gray laminated limestone, which ranges in thickness from 25 to 65 feet (Driscoll et al., 2002). The Minnekahta is considered a major aquifer in parts of the Black Hills area but does not supply any known water wells locally.

### Unkpapa/Sundance Formation

The Sundance Formation consists of greenish-gray shale with thin limestone lenses; glauconitic sandstone, with red sandstone near the middle of the formation. The Sundance ranges from 250 to 450 feet thick (Carter et al., 2003). The Unkpapa Sandstone is a massive fine-grained sandstone, 0 to 225 feet thick (Carter et al., 2003). A potentiometric surface map of the Unkpapa is presented as

figure D-14a. The Unkpapa/Sundance is considered a minor aquifer in the area. Local water quality data from wells located within the Dewey-Burdock Project are presented in Table D-3.

#### Inyan Kara Group

Several sandstone units compose the lower Cretaceous aquifer, which is known as the Inyan Kara aquifer in South Dakota. These units are the Lakota and Fall River Formations and the Lakota is divided into the Chilson, Minnewaste, and Fuson Members. Some authors include the Minnewaste Limestone Member regionally, but it is not present below the project area. Generally, water in the Inyan Kara is confined by several thick shale layers of the Graneros Group (including the Skull Creek Shale), except in outcrop areas around structural uplifts, such as the Black Hills Uplift. Regionally, groundwater in the Inyan Kara moves from high-altitude recharge areas to discharge areas in eastern North Dakota and South Dakota. Although the aquifer is wide-spread, it contains little fresh water except in small areas in central and south-central Montana and north and east of the Black Hills uplift. Water in the Inyan Kara is saline in the deeper parts of the Williston and Powder River Basins (Driscoll et al., 2002). Table D-4 presents local water quality data from wells located within the Dewey-Burdock Project. A structure contour map of the Inyan Kara is included as Figure D-15. Isopach maps of each of the units that compose the Inyan Kara are included as Figures D-16, D-17, and D-18. A potentiometric surface map of the Fall River Aquifer is presented as Figure D-19.

Figure D-20 is a cross-section location map that shows A - A' (Figure D-21) and B - B' (Figure D-22) which show the vertical extent of the USDWs across the project area. The lowermost formations (Madison, Englewood, and Deadwood) are not shown due to the lack of deep well logs.

TABLE D-1 Local Water Quality Data - Madison Formation

| Summary of Madison well data, Edgemont city water |           |             |           |           |           |           |           |           |           |           |        |         |         |          |
|---|-----------|-------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|--------|---------|---------|----------|
|   |           | Well ID     | BNR/TVA   | well 2    | well 4    | well 5    | TVA       | well 2    | well 4    | well 5    | Mean   | Minimum | Maximum | Std. Dev |
|   |           | Sample Date | 11/6/2002 | 11/6/2002 | 11/6/2002 | 11/6/2002 | 5/23/2000 | 5/23/2000 | 5/23/2000 | 5/23/2000 |        |         |         |          |
| Component   |           | units       |           |           |           |           |           |           |           |           |        |         |         |          |
| Physical properties                               |           |             |           |           |           |           |           |           |           |           |        |         |         |          |
| Conductivity                                      | Cond.     | umhos/cm    | 1154      | 1671      | 1785      | 2140      | 1300      | 1700      | 1800      | 2300      | 1731.3 | 1154.0  | 2300.0  | 382.1    |
| Hardness  |           |             | 406       | 503       | 528       | 580       | 410       | 460       | 500       | 560       | 493.4  | 406.0   | 580.0   | 64.3     |
| pH  | pH        |             | 7.81      | 7.7       | 7.73      | 7.66      | 7.15      | 7.23      | 7.26      | 7.37      | 7.5    | 7.2     | 7.8     | 0.3      |
| TDS   | TDS       | mg/L        | 726       | 1047      | 1101      | 1333      | 690       | 980       | 940       | 1000      | 977.1  | 690.0   | 1333.0  | 205.0    |
| TSS   | TSS       | mg/L        |           |           |           |           |           |           |           |           |        |         |         |          |
| Turbidity   | Turbidity | NTU         |           |           |           |           |           |           |           |           |        |         |         |          |
| Acidity   | Acidity   |             |           |           |           |           |           |           |           |           |        |         |         |          |
| Alkalinity  | CaCO3     |             | 188       | 181       | 182       | 180       | 170       | 160       | 160       | 170       | 173.9  | 160.0   | 188.0   | 10.5     |
| Carbonate   | CO3       | mg/L        |           |           |           |           |           |           |           |           |        |         |         |          |
| Bicarbonate                                       | HCO3      | mg/L        | 229       | 221       | 222       | 220       | 210       | 200       | 200       | 210       | 214.0  | 200.0   | 229.0   | 10.7     |
| Chloride  | Cl        | mg/L        | 185       | 255       | 300       | 385       | 150       | 250       | 270       | 360       | 269.4  | 150.0   | 385.0   | 79.7     |
| Cyanide   | CN        | mg/L        |           |           |           |           |           |           |           |           |        |         |         |          |
| Flouride  | F         | mg/L        | 0.843     | 1.1       | 1.07      | 1.32      | 0.9       | 1.05      | 1.03      | 1.2       | 1.1    | 0.8     | 1.3     | 0.2      |
| Nitrogen, Ammonia                                 | NH3       | mg/L        |           |           |           |           |           |           |           |           |        |         |         |          |
| Nitrogen, Nitrate                                 | NO3       | mg/L        | 0.211     | 0.086     | 0.063     | <.05      | 0.15      | 0.16      | 0.16      | <.1       | 0.1    | 0.1     | 0.2     | 0.1      |
| Nitrogen, Nitrite                                 | NO2       | mg/L        |           |           |           |           | <.01      | <.01      | <.01      | <.01      |        | 0.0     | 0.0     |          |
| Sulfate   | SO4       | mg/L        | 211       | 295       | 309       | 353       | 210       | 300       | 340       | 390       | 301.0  | 210.0   | 390.0   | 64.0     |
| Metals  |           |             |           |           |           |           |           |           |           |           |        |         |         |          |
| Aluminum  | Al        | mg/L        |           |           |           |           |           |           |           |           |        |         |         |          |
| Arsenic   | As        | mg/L        | 0.006     | 0.01      | 0.01      | 0.008     |           |           |           |           | 0.0085 | 0.0     | 0.0     | 0.0019   |
| Calcium   | Ca        | mg/L        | 115       | 150       | 156       | 175       | 100       | 120       | 130       | 140       | 135.8  | 100.0   | 175.0   | 24.4     |
| Iron  | Fe        | mg/L        | 0.05      | 0.091     | <.05      | 2.53      | <.05      | 0.09      | <.05      | 2.6       | 1.1    | 0.1     | 2.6     | 1.4      |
| Magnesium   | Mg        | mg/L        | 28.8      | 31.1      | 33.7      | 34.8      | 30        | 32        | 35        | 36        | 32.7   | 28.8    | 36.0    | 2.6      |
| Manganese   | Mn        | mg/L        | 0.05      | 0.05      | <.05      | <.05      | <.03      | <.03      | <.03      | 0.05      | 0.05   | 0.1     | 0.1     | 0.00     |
| Mercury   | Hg        | mg/L        |           |           |           |           |           |           |           |           |        |         |         |          |
| Lead  | Pb        | mg/L        |           |           |           |           |           |           |           |           |        |         |         |          |
| Molybdenum  | Mo        | mg/L        |           |           |           |           |           |           |           |           |        |         |         |          |
| Potassium   | K         | mg/L        | 10.6      | 17.3      | 17.9      | 23        | 12        | 19        | 20        | 24        | 18.0   | 10.6    | 24.0    | 4.7      |
| Selenium  | Se        | mg/L        |           |           |           |           |           |           |           |           |        |         |         |          |
| Sodium  | Na        | mg/L        | 86.9      | 161       | 174       | 228       | 88        | 150       | 170       | 200       | 157.2  | 86.9    | 228.0   | 49.4     |

Source: Summary of Madison well data, Edgemont city water <http://www.sdgs.usd.edu/other/db.html>

**TABLE D-2 Local Water Quality Data - Minnelusa Formation**

| API Number | Location |          |       |          |            | County     | Formation Sampled | Sample Method | Test Interval |               | TDS (mg/L) |
|------------|----------|----------|-------|----------|------------|------------|-------------------|---------------|---------------|---------------|------------|
|            | Section  | Township | Range | Latitude | Longitude  |            |                   |               | Top (feet)    | Bottom (feet) |            |
| 4003305005 | 34       | 6S       | 2E    | 43.48664 | -103.86925 | Custer     | Minnelusa         | DST           | 1,338         | 1,375         | 18,814     |
| 4003305010 | 34       | 6S       | 2E    | 43.48814 | -103.86781 | Custer     | Minnelusa         | Production    | 1,368         | 1,388         | 13,512     |
| 4003305010 | 34       | 6S       | 2E    | 43.48814 | -103.86781 | Custer     | Minnelusa         | Wellhead      | 1,356         | --            | 7,740      |
| 4003305015 | 34       | 6S       | 2E    | 43.49021 | -103.86926 | Custer     | Minnelusa         | Separator     | 713           | --            | 7,429      |
| 4003305035 | 30       | 5S       | 2E    | 43.58112 | -103.93146 | Custer     | Minnelusa         | Bailer        | 845           | 851           | 4,288      |
| 4004705067 | 15       | 9S       | 2E    | 43.26232 | -103.87392 | Fall River | Minnelusa         | DST           | 2,692         | 2,707         | 24,823     |
| 4004705067 | 15       | 9S       | 2E    | 43.26232 | -103.87392 | Fall River | Minnelusa         | DST           | 2,692         | 2,707         | 24,422     |
| 4004705067 | 15       | 9S       | 2E    | 43.26232 | -103.87392 | Fall River | Minnelusa         | WLT           | 2,230         | 2,234         | 9,803      |
| 4004705089 | 21       | 7S       | 1E    | 43.42595 | -103.99711 | Fall River | Minnelusa         | DST           | 2,390         | 2,400         | 21,391     |
| 4004705089 | 21       | 7S       | 1E    | 43.42595 | -103.99711 | Fall River | Minnelusa         | DST           | 2,390         | 2,400         | 17,279     |
| 4004705089 | 21       | 7S       | 1E    | 43.42595 | -103.99711 | Fall River | Minnelusa         | DST           | 2,390         | 2,400         | 16,652     |
| 4004705092 | 21       | 7S       | 2E    | 43.42964 | -103.88318 | Fall River | Minnelusa         | Unknown       | 1,415         | 1,418         | 10,183     |
| 40000185   | 34       | 6S       | 2E    | 43.48480 | -103.86630 | Custer     | Minnelusa         | Separator     | 713           | --            | 7,427      |
| 40000183   | 34       | 6S       | 2E    | 43.48480 | -103.86630 | Custer     | Minnelusa         | Separator     | 680           | --            | 6,968      |

Notes:

-- - Data not provided.

Shading indicates duplicate samples.

Source: USGS Produced waters Database; <http://energy.cr.usgs.gov/prov/prodwat/data.htm>

TABLE D-3 Local Water Quality Data - Unkpapa/Sundance Formation

| Well #635                          |               |               |               |               |
|------------------------------------|---------------|---------------|---------------|---------------|
| Analyte                            | 9/26/07 18:08 | 11/27/07 8:25 | 2/10/08 14:55 | 4/29/08 19:00 |
| A/C Balance (± 5) (%)              | -1.14         | -0.831        | -0.25         | 3.52          |
| Alkalinity-Total as CaCO3 (mg/L)   | 124           | 118           | 120           | 118           |
| Aluminum-Dissolved (mg/L)          | <0.1          | <0.1          | <0.1          | <0.1          |
| Ammonia (mg/L)                     | 0.1           | 0.4           | 0.5           | 0.5           |
| Anions (meq/L)                     | 30.4          | 31.6          | 33.7          | 32.8          |
| Antimony-Total (mg/L)              |               |               | <0.003        | <0.003        |
| Arsenic-Dissolved (mg/L)           | <0.001        | <0.001        | <0.001        | <0.001        |
| Arsenic-Total (mg/L)               |               |               | <0.001        | 0.001         |
| Barium-Dissolved (mg/L)            | <0.1          | <0.1          | <0.1          | <0.1          |
| Barium-Total (mg/L)                |               |               | <0.1          | <0.1          |
| Beryllium-Total (mg/L)             |               |               | <0.001        | <0.001        |
| Bicarbonate as HCO3 (mg/L)         | 151           | 144           | 146           | 144           |
| Boron-Dissolved (mg/L)             | 0.4           | 0.4           | 0.5           | 0.4           |
| Boron-Total (mg/L)                 |               |               | 0.5           | 0.4           |
| Cadmium-Dissolved (mg/L)           | <0.005        | <0.005        | <0.005        | <0.005        |
| Cadmium-Total (mg/L)               |               |               | <0.005        | <0.005        |
| Calcium-Dissolved (mg/L)           | 110           | 120           | 132           | 136           |
| Carbonate as CO3 (mg/L)            | <5            | <5            | <5            | <5            |
| Cations (meq/L)                    | 29.8          | 31.1          | 33.5          | 35.2          |
| Chloride (mg/L)                    | 24            | 23            | 26            | 20            |
| Chromium-Dissolved (mg/L)          | <0.05         | <0.05         | <0.05         | <0.05         |
| Chromium-Total (mg/L)              |               |               | <0.05         | <0.05         |
| Conductivity @ 25 C (umhos/cm)     | 2890          | 2830          | 2950          | 2810          |
| Copper-Dissolved (mg/L)            | <0.01         | <0.01         | <0.01         | <0.01         |
| Copper-Total (mg/L)                |               |               | <0.01         | <0.01         |
| Fluoride (mg/L)                    | 0.3           | 0.3           | 0.4           | 0.4           |
| Gross Alpha-Dissolved (pCi/L)      | 2.5           | 4.4           | 14.8          | 13.2          |
| Gross Beta-Dissolved (pCi/L)       | 4.3           | 6.3           | 10            | -8            |
| Gross Gamma-Dissolved (pCi/L)      | 960           | 1000          | 91            |               |
| Iron-Dissolved (mg/L)              | <0.03         | <0.03         | <0.03         | <0.03         |
| Iron-Total (mg/L)                  |               |               | 1.11          | 1.08          |
| Lead 210-Dissolved (pCi/L)         | <1            | 1.7           | <1            |               |
| Lead 210-Suspended (pCi/L)         | <1            | 5.1           | <1            | -9.6          |
| Lead 210-Total (pCi/L)             | <1            |               |               |               |
| Lead-Dissolved (mg/L)              | <0.001        | 0.003         | <0.001        | <0.001        |
| Lead-Total (mg/L)                  |               |               | <0.001        | <0.001        |
| Magnesium-Dissolved (mg/L)         | 44.3          | 49            | 52.3          | 54.1          |
| Manganese-Dissolved (mg/L)         | 0.06          | 0.07          | 0.06          | 0.06          |
| Manganese-Total (mg/L)             |               |               | 0.06          | 0.05          |
| Mercury-Dissolved (mg/L)           | <0.001        | <0.001        | <0.001        | <0.001        |
| Mercury-Total (mg/L)               | <0.0002       | <0.001        | <0.001        | <0.001        |
| Molybdenum-Dissolved (mg/L)        | <0.1          | <0.1          | <0.1          | <0.1          |
| Molybdenum-Total (mg/L)            |               |               | 0.01          | <0.1          |
| Nickel-Dissolved (mg/L)            | <0.05         | <0.05         | <0.05         | <0.05         |
| Nickel-Total (mg/L)                |               |               | <0.05         | <0.05         |
| Nitrogen, Nitrate as N (mg/L)      | <0.1          | <0.1          | <0.1          | <0.05         |
| Nitrogen, Nitrite as N (mg/L)      | <0.1          | <0.1          | <0.1          | <0.05         |
| Oxidation-Reduction Potential (mV) |               | 270           | 129.4         | 180           |
| pH                                 | 7.72          | 7.64          | 7.91          | 8.2           |
| Polonium 210-Dissolved (pCi/L)     | <1            | 1.9           | <1            | 1.1           |
| Polonium 210-Suspended (pCi/L)     | <1            | <1            | <1            |               |
| Polonium 210-Total (pCi/L)         | <1            |               |               |               |
| Potassium-Dissolved (mg/L)         | 7.8           | 8.3           | 8.2           | 7.3           |
| Radium 226-Dissolved (pCi/L)       | 1.6           | 0.8           | 1.3           |               |
| Radium 226-Suspended (pCi/L)       | 0.8           | <0.2          | 0.6           | 0.3           |
| Radium 226-Total (pCi/L)           | 2.4           |               |               |               |

TABLE D-3 Local Water Quality Data - Unkapa/Sundance Formation

| Well #635                                 |               |               |               |               |
|---|---------------|---------------|---------------|---------------|
| Analyte                                   | 9/26/07 18:08 | 11/27/07 8:25 | 2/10/08 14:55 | 4/29/08 19:00 |
| Radon 222-Total (pCi/L)                   |               | 902           | 806           | 1070          |
| Selenium-Dissolved (mg/L)                 | 0.001         | <0.001        | <0.001        | <0.001        |
| Selenium-IV-Dissolved (mg/L)              |               | 0.001         | <0.001        | <0.001        |
| Selenium-Total (mg/L)                     |               |               | <0.001        | 0.001         |
| Selenium-VI-Dissolved (mg/L)              |               | <0.001        | <0.001        | <0.001        |
| Silica-Dissolved (mg/L)                   | 8.6           | 9             | 10            | 4.9           |
| Silver-Dissolved (mg/L)                   | <0.005        | <0.005        | <0.005        | <0.005        |
| Silver-Total (mg/L)                       |               |               | <0.005        | <0.005        |
| Sodium Adsorption Ratio (SAR) (meq/L)     |               | 9.3           | 9.6           | 10            |
| Sodium-Dissolved (mg/L)                   | 470           | 480           | 515           | 545           |
| Solids-Total Dissolved Calculated (mg/L)  | 2040          | 2120          | 2270          | 2280          |
| Solids-Total Dissolved TDS @ 180 C (mg/L) | 2200          | 2300          | 2300          | 2200          |
| Strontium-Total (mg/L)                    |               |               | 4.2           | 4.6           |
| Sulfate (mg/L)                            | 1500          | 1370          | 1470          | 1430          |
| TDS Balance (0.80 - 1.20) (dec.%)         | 1.09          | 1.08          | 1.03          | 0.98          |
| Thallium-Total (mg/L)                     |               |               | <0.001        | <0.001        |
| Thorium 230-Dissolved (pCi/L)             | <0.2          | <0.2          | <0.2          | 0.2           |
| Thorium 230-Suspended (pCi/L)             | <0.2          | <0.2          | <0.2          | 0.1           |
| Thorium 230-Total (pCi/L)                 | <0.2          |               |               |               |
| Thorium 232-Dissolved (pCi/L)             | <0.005        | <0.005        | <0.005        | <0.005        |
| Uranium-Dissolved (mg/L)                  | 0.002         | 0.002         | 0.0021        | 0.0017        |
| Uranium-Suspended (mg/L)                  | <0.0003       | <0.0003       | <0.0003       | <0.0003       |
| Uranium-Total (mg/L)                      | 0.002         |               | 0.0021        | 0.0017        |
| Vanadium-Dissolved (mg/L)                 | <0.1          | <0.1          | <0.1          | <0.1          |
| Zinc-Dissolved (mg/L)                     | <0.01         | 0.02          | <0.01         | <0.01         |
| Zinc-Total (mg/L)                         |               |               | <0.01         | <0.01         |

Source: Powertech 2008 Class III UIC Permit Application, Appendix F

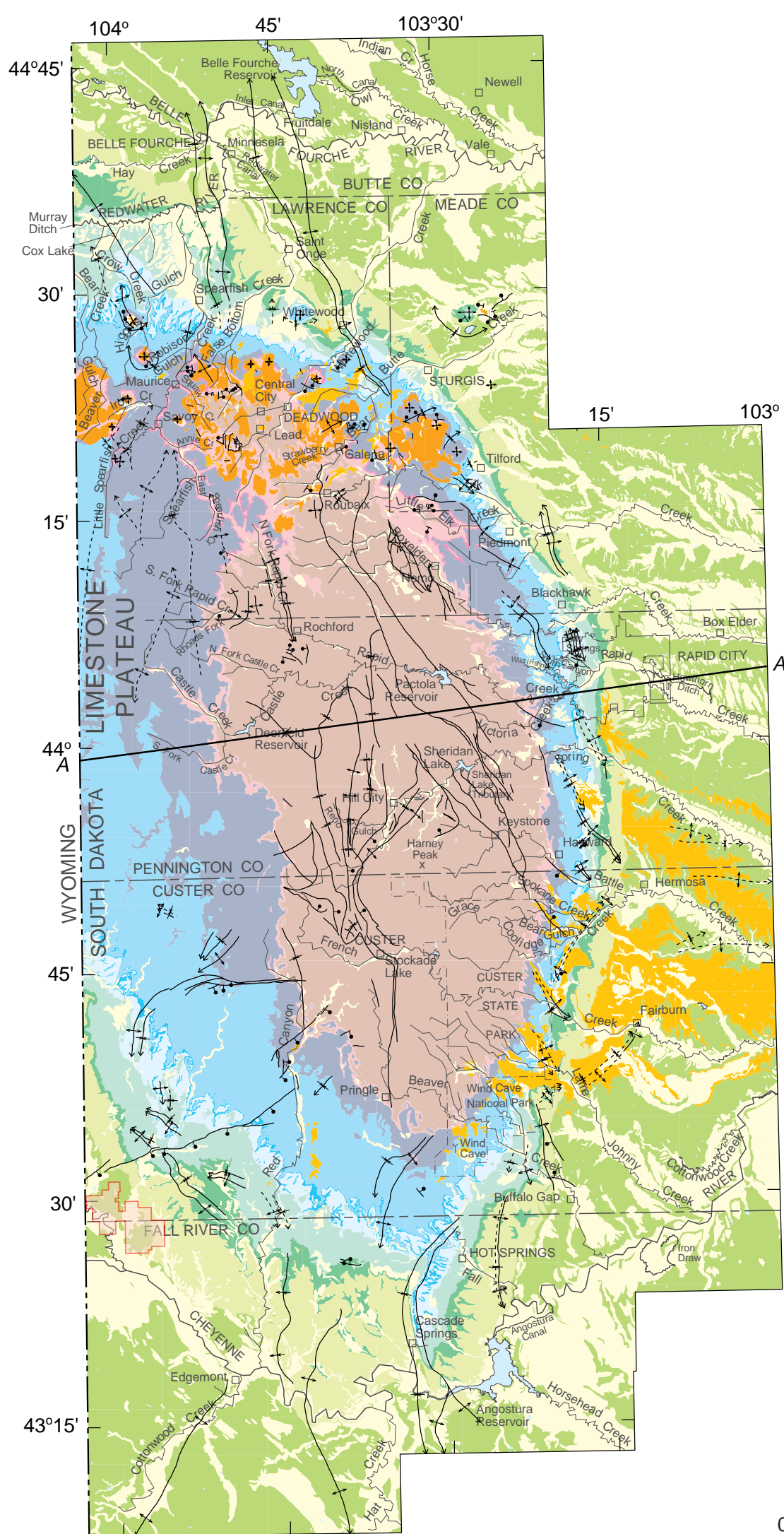
**TABLE D-4 Local Water Quality Data - Inyan Kara Group (Lakota and Fall River Formations)**

|  | Well                   | Mean      |      |      | Minimum   |      |      | Maximum   |      |      |
|--|------------------------|-----------|------|------|-----------|------|------|-----------|------|------|
|  |                        | Powertech | TVA  | RPD  | Powertech | TVA  | RPD  | Powertech | TVA  | RPD  |
| Alkalinity as CaCO <sub>3</sub> , mg/L | 2                      | 181       | 219  | 19%  | 88        | 200  | 78%  | 214       | 242  | 12%  |
|  | 7                      | 171       | 181  | 6%   | 170       | 171  | 1%   | 176       | 191  | 8%   |
|  | 8                      | 166       | 178  | 7%   | 156       | 166  | 6%   | 178       | 194  | 9%   |
|  | 13                     | 159       | 173  | 8%   | 142       | 160  | 12%  | 170       | 196  | 14%  |
|  | 16                     | 153       | 152  | 1%   | 148       | 144  | 3%   | 160       | 157  | 2%   |
|  | 18                     | 179       | 196  | 9%   | 172       | 180  | 5%   | 184       | 238  | 26%  |
|  | 42                     | 178       | 188  | 5%   | 174       | 179  | 3%   | 180       | 204  | 13%  |
|  | 4002                   | 140       | 158  | 12%  | 138       | 144  | 4%   | 144       | 202  | 34%  |
|  | 7002                   | 261       | 261  | 0%   | 250       | 210  | 17%  | 280       | 300  | 7%   |
|  | Conductivity, uS/cm    | 2         | 2285 | 1547 | 39%       | 1500 | 1450 | 3%        | 4400 | 1750 |
| 7                                      |                        | 1542      | 1338 | 14%  | 1440      | 1325 | 8%   | 1650      | 1350 | 20%  |
| 8                                      |                        | 1450      | 1385 | 5%   | 1420      | 1285 | 10%  | 1560      | 1450 | 7%   |
| 13                                     |                        | 1292      | 1274 | 1%   | 1140      | 1100 | 4%   | 1420      | 1400 | 1%   |
| 16                                     |                        | 1063      | 1162 | 9%   | 925       | 1150 | 22%  | 1260      | 1175 | 7%   |
| 18                                     |                        | 1412      | 1379 | 2%   | 1330      | 1300 | 2%   | 1470      | 1420 | 3%   |
| 42                                     |                        | 1408      | 1353 | 4%   | 1310      | 1200 | 9%   | 1510      | 1400 | 8%   |
| 4002                                   |                        | 1220      | 1161 | 5%   | 1130      | 1100 | 3%   | 1340      | 1195 | 11%  |
| 7002                                   |                        | 2328      | 2339 | 0%   | 2200      | 1925 | 13%  | 2480      | 2500 | 1%   |
| pH                                     |                        | 2         | 7.91 | 7.7  | 3%        | 7.85 | 7.16 | 9%        | 7.94 | 8.2  |
|  | 7                      | 8.11      | 8.5  | 5%   | 8.05      | 8.3  | 3%   | 8.17      | 8.7  | 6%   |
|  | 8                      | 7.95      | 7.87 | 1%   | 7.93      | 7.59 | 4%   | 7.97      | 8.5  | 6%   |
|  | 13                     | 7.9       | 7.76 | 2%   | 7.75      | 7.48 | 4%   | 8.05      | 8.1  | 1%   |
|  | 16                     | 7.46      | 7.34 | 2%   | 7.38      | 7.31 | 1%   | 7.57      | 7.39 | 2%   |
|  | 18                     | 8.08      | 7.94 | 2%   | 8.02      | 7.69 | 4%   | 8.11      | 8.4  | 4%   |
|  | 42                     | 8.02      | 7.94 | 1%   | 7.95      | 7.67 | 4%   | 8.08      | 8.4  | 4%   |
|  | 4002                   | 7.83      | 7.75 | 1%   | 7.65      | 7.51 | 2%   | 8.02      | 8.5  | 6%   |
|  | 7002                   | 7.36      | 7.44 | 1%   | 7.22      | 7.14 | 1%   | 7.56      | 8    | 6%   |
|  | Total Dissolved Solids | 2         | 1750 | 1043 | 51%       | 1100 | 1004 | 9%        | 3600 | 1113 |
| 7                                      |                        | 999       | 1081 | 8%   | 896       | 1058 | 17%  | 1050      | 1104 | 5%   |
| 8                                      |                        | 1000      | 965  | 4%   | 940       | 860  | 9%   | 1100      | 1130 | 3%   |
| 13                                     |                        | 878       | 886  | 1%   | 850       | 792  | 7%   | 890       | 1006 | 12%  |
| 16                                     |                        | 814       | 846  | 4%   | 760       | 796  | 5%   | 940       | 894  | 5%   |
| 18                                     |                        | 958       | 909  | 5%   | 940       | 520  | 58%  | 990       | 1118 | 12%  |
| 42                                     |                        | 950       | 939  | 1%   | 930       | 888  | 5%   | 980       | 1033 | 5%   |
| 4002                                   |                        | 818       | 773  | 6%   | 790       | 740  | 7%   | 850       | 805  | 5%   |
| 7002                                   |                        | 1875      | 1843 | 2%   | 1800      | 1690 | 6%   | 1900      | 1970 | 4%   |

RPD (Relative Percent Difference) = The absolute difference divided by the average.

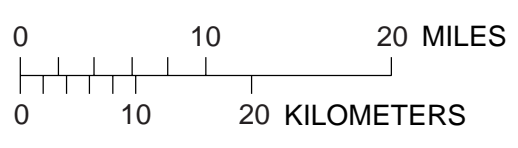
Source: Table 2.7-45: Comparison of Statistics for Selected Constituents between Historic TVA Data and current Powertech Data (2009 Powertech NRC Application)





| Hydrogeologic Units                       | Stratigraphic Units | Map Units   |
|---|---------------------|---|
| Unconsolidated units                      | QTac                | Alluvium and colluvium, undifferentiated                        |
| White River aquifer                       | Tw                  | White River Group   |
| Tertiary intrusive units                  | Tui                 | Undifferentiated intrusive igneous rocks                        |
| Cretaceous-sequence confining unit        | Kps                 | Pierre Shale to Skull Creek Shale, undifferentiated             |
| Inyan Kara aquifer                        | Kik                 | Inyan Kara Group  |
| Jurassic-sequence semiconfining unit      | Ju                  | Morrison Formation to Gypsum Spring Formation, undifferentiated |
| Spearfish confining unit                  | TrPs                | Spearfish Formation   |
| Minnekahta aquifer                        | Pmk                 | Minnekahta Limestone  |
| Opeche confining unit                     | Po                  | Opeche Shale  |
| Minnelusa aquifer                         | PPm                 | Minnelusa Formation   |
| Madison aquifer                           | MDme                | Madison (Pahasapa) Limestone and Englewood Formation            |
| Ordovician-sequence semiconfining unit    | Ou                  | Whitewood Formation and Winnipeg Formation                      |
| Deadwood aquifer                          | OCd                 | Deadwood Formation  |
| Precambrian igneous and metamorphic units | pCu                 | Undifferentiated metamorphic and igneous rocks                  |

- A — A'** LINE OF GEOLOGIC SECTION
- · · · · · FAULT--Dashed where approximated. Bar and ball on downthrown side.
  - + · · · · · ANTICLINE--Showing trace of axial plane and direction of plunge. Dashed where approximated.
  - - · · · · · SYNCLINE--Showing trace of axial plane and direction of plunge. Dashed where approximated.
  - | · · · · · MONOCLINE--Showing trace of axial plane. Dashed where approximated.
  - + DOME--Symbol size approximately proportional to size of dome. Dome asymmetry indicated by arrow length.



Base modified from U.S. Geological Survey digital data, 1:100,000  
Rapid City, Office of City Engineer map, 1:18,000, 1996  
Universal Transverse Mercator projection, zone 13

**Legend**

Dewey-Burdock Permit Boundary



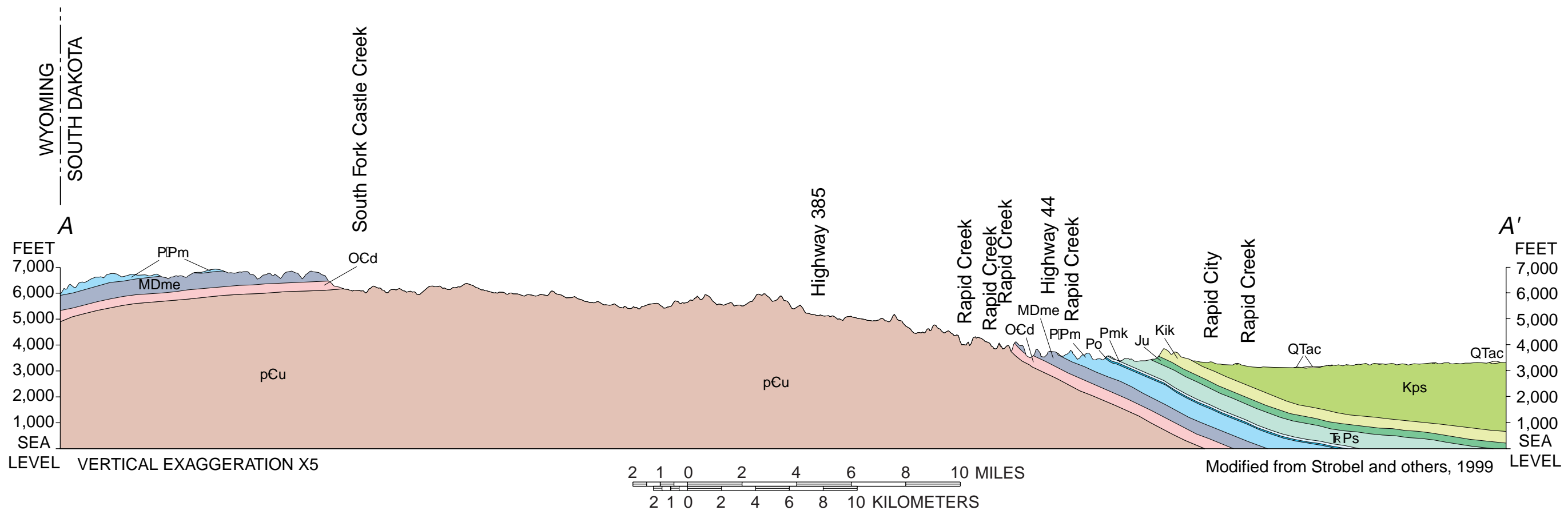
From:  
Water-Resources Investigations Report 01-4194  
by Joyce E. Williamson and Janet M. Carter, 2001

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Figure D-1  
Distribution of Hydrogeologic Units  
in the Black Hills Area  
2010 Dewey-Burdock Class V Permit

|                           |                     |
|---------------------------|---------------------|
| Scale: See Bar Scale      | Date: March 2010    |
| 2010_DB_Class_Fig_D-01.ai | By: JLM Checked: HD |

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| EXPLANATION                               |                     |   |
|---|---------------------|---|
| Hydrogeologic Units                       | Stratigraphic Units | Map Units   |
| Unconsolidated units                      | QTac                | Alluvium and colluvium, undifferentiated                        |
| White River aquifer                       | Tw                  | White River Group   |
| Tertiary intrusive units                  | Tui                 | Undifferentiated intrusive igneous rocks                        |
| Cretaceous-sequence confining unit        | Kps                 | Pierre Shale to Skull Creek Shale, undifferentiated             |
| Inyan Kara aquifer                        | Kik                 | Inyan Kara Group  |
| Jurassic-sequence semiconfining unit      | Ju                  | Morrison Formation to Gypsum Spring Formation, undifferentiated |
| Spearfish confining unit                  | TPs                 | Spearfish Formation   |
| Minnekahta aquifer                        | Pmk                 | Minnekahta Limestone  |
| Opeche confining unit                     | Po                  | Opeche Shale  |
| Minnelusa aquifer                         | PPm                 | Minnelusa Formation   |
| Madison aquifer                           | MDme                | Madison (Pahasapa) Limestone and Englewood Formation            |
| Ordovician-sequence semiconfining unit    | Ou                  | Whitewood Formation and Winnipeg Formation                      |
| Deadwood aquifer                          | OCd                 | Deadwood Formation  |
| Precambrian igneous and metamorphic units | pCu                 | Undifferentiated metamorphic and igneous rocks                  |

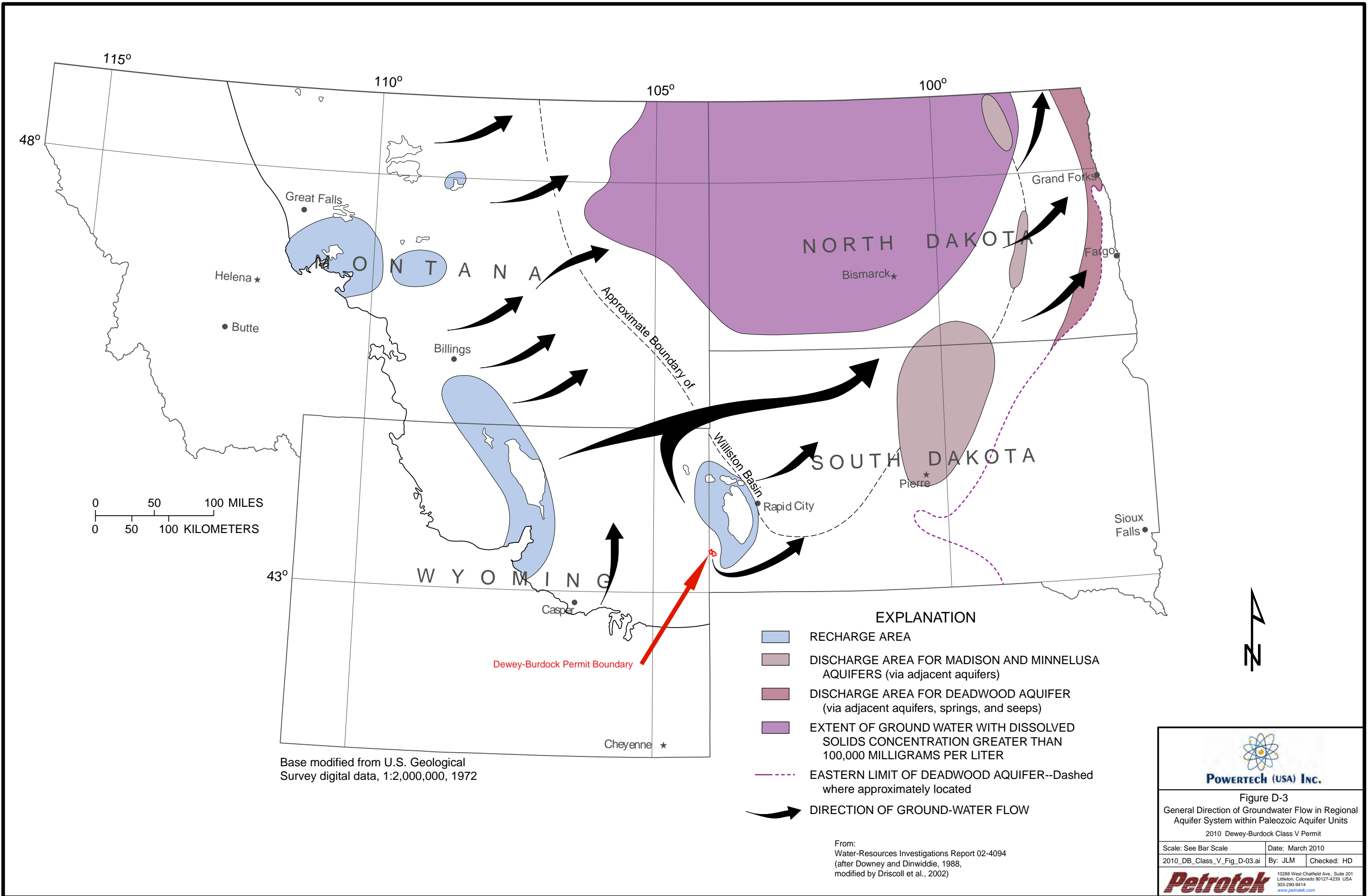
From:  
Water-Resources Investigations Report 01-4194  
(after Strobel et al., 1999, Modified by Driscoll et al., 2002)

Figure D-2  
Generalized East-West Geologic Cross Section through Black Hills Uplift (A-A')


2010 Dewey-Burdock Class V Permit

|                            |                     |
|----------------------------|---------------------|
| Scale: See Bar Scale       | Date: March 2010    |
| 2010_DB_Class_V_Fig_D-2.ai | By: JLM Checked: HD |

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Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972



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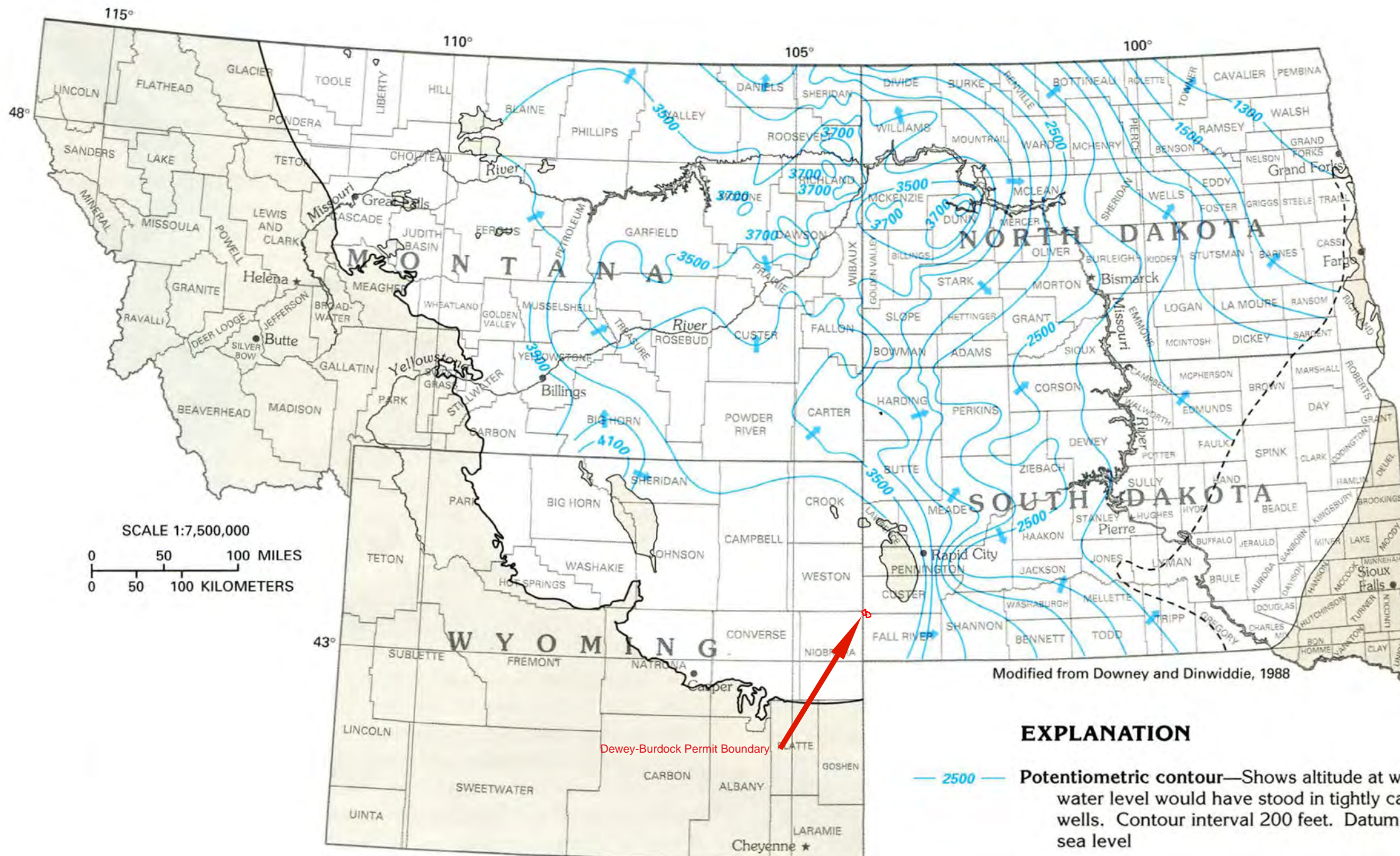
Figure D-3  
General Direction of Groundwater Flow in Regional Aquifer System within Paleozoic Aquifer Units  
2010 Dewey-Burdock Class V Permit

|                             |                        |
|-----------------------------|------------------------|
| Scale: See Bar Scale        | Date: March 2010       |
| 2010_DB_Class_V_Fig_D-03.ai | By: JLM    Checked: HD |



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Modified from Downey and Dinwiddie, 1988

**EXPLANATION**

- 2500 — Potentiometric contour—Shows altitude at which water level would have stood in tightly cased wells. Contour interval 200 feet. Datum is sea level
- Limit of lower Paleozoic aquifers—Dashed where approximately located
- ➔ Direction of ground-water movement

Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972


From:  
Ground Water Atlas of the United States,  
Segment 8 MT, SD, ND & WY,  
Hydrologic Investigations Atlas 730-I USGS  
(by Whitehead, 1996)



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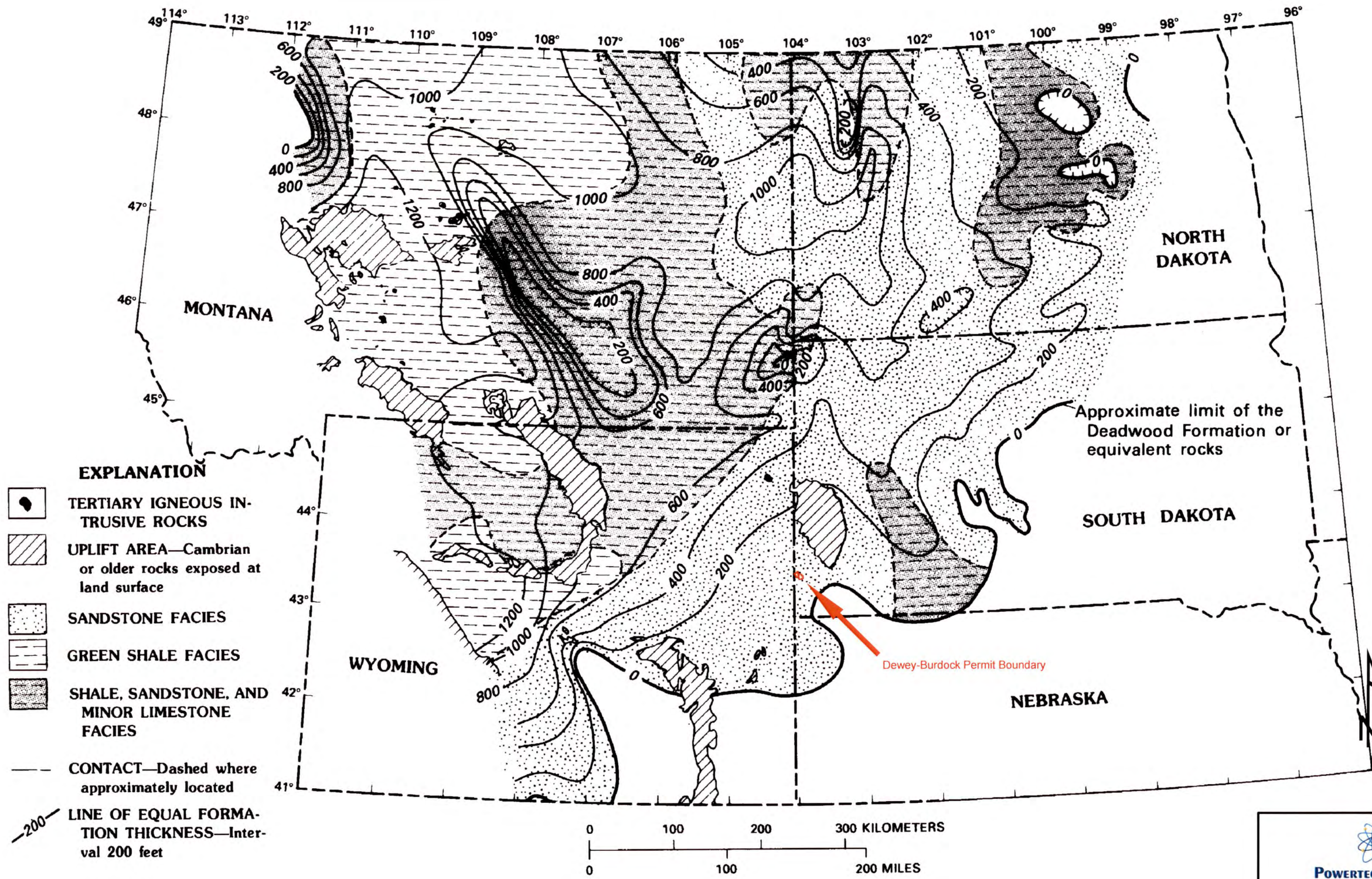
Figure D-4  
Regional Groundwater Flow in Lower Paleozoic  
Aquifer System, Powder River and Williston Basins  
2010 Dewey-Burdock Class V Permit

|                             |         |                  |  |
|-----------------------------|---------|------------------|--|
| Scale: See Bar Scale        |         | Date: March 2010 |  |
| 2010_DB_Class_V_Fig_D-04.ai | By: JLM | Checked: HD      |  |



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- EXPLANATION**
- TERTIARY IGNEOUS INTRUSIVE ROCKS
  - UPLIFT AREA—Cambrian or older rocks exposed at land surface
  - SANDSTONE FACIES
  - GREEN SHALE FACIES
  - SHALE, SANDSTONE, AND MINOR LIMESTONE FACIES
  - CONTACT—Dashed where approximately located
  - LINE OF EQUAL FORMATION THICKNESS—Interval 200 feet

0 100 200 300 KILOMETERS  
 0 100 200 MILES

From:  
 Geological Survey Professional Paper 1273-A  
 Peterson, 1984


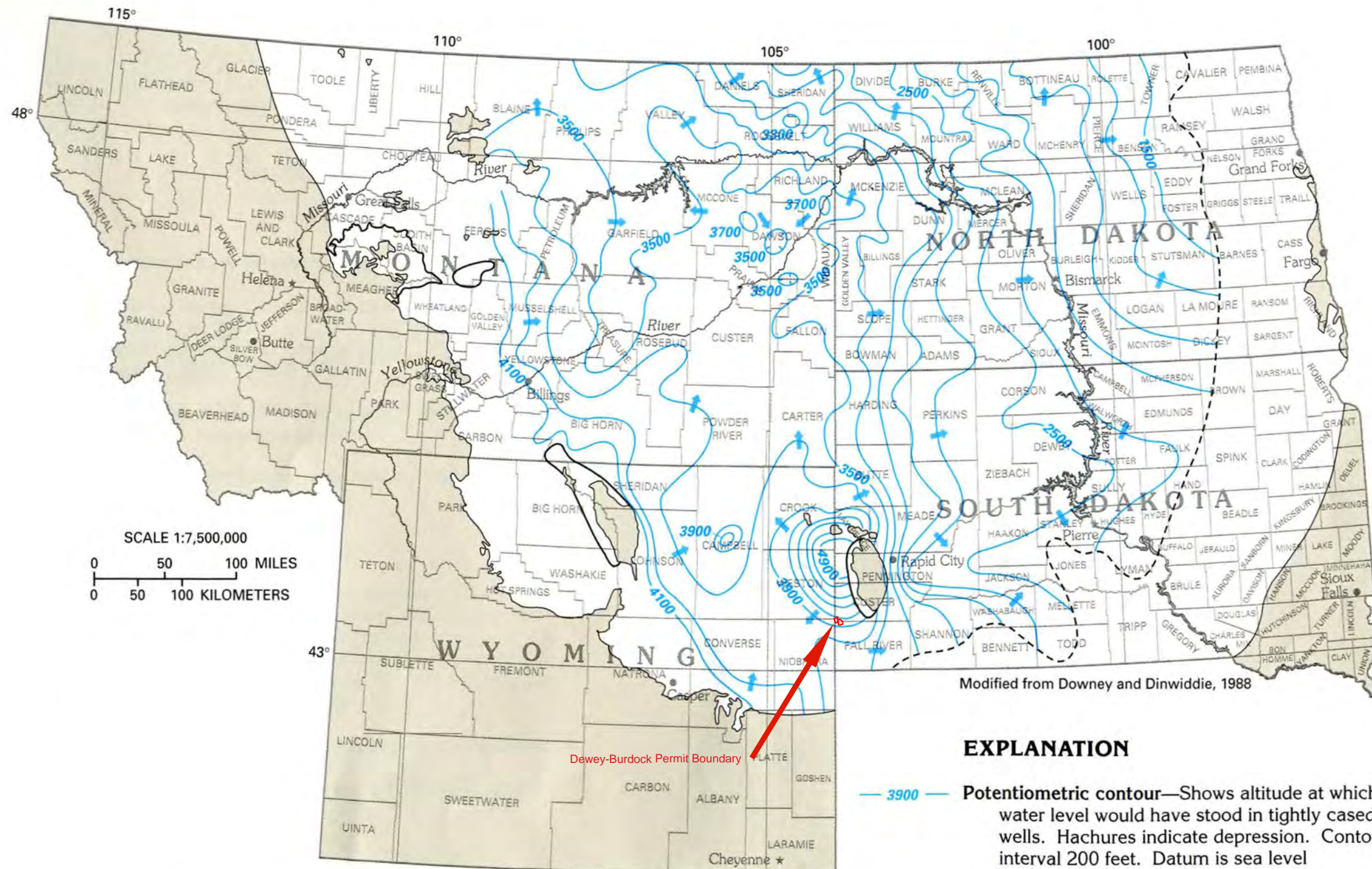
  
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Figure D-5  
 Isopach Map,  
 Deadwood Formation  
 2010 Dewey-Burdock Class V Permit

|                             |                        |
|-----------------------------|------------------------|
| Scale: See Bar Scale        | Date: March 2010       |
| 2010_DB_Class_V_Fig_D-05.ai | By: JLM    Checked: HD |

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Modified from Downey and Dinwiddie, 1988

Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972

**EXPLANATION**

- 3900 — Potentiometric contour—Shows altitude at which water level would have stood in tightly cased wells. Hachures indicate depression. Contour interval 200 feet. Datum is sea level
- Limit of upper Paleozoic aquifers—Dashed where approximately located
- ➔ Direction of ground-water movement

From:  
Ground Water Atlas of the United States,  
Segment 8 MT, SD, ND & WY,  
Hydrologic Investigations Atlas 730-I USGS  
(by Whitehead, 1996)



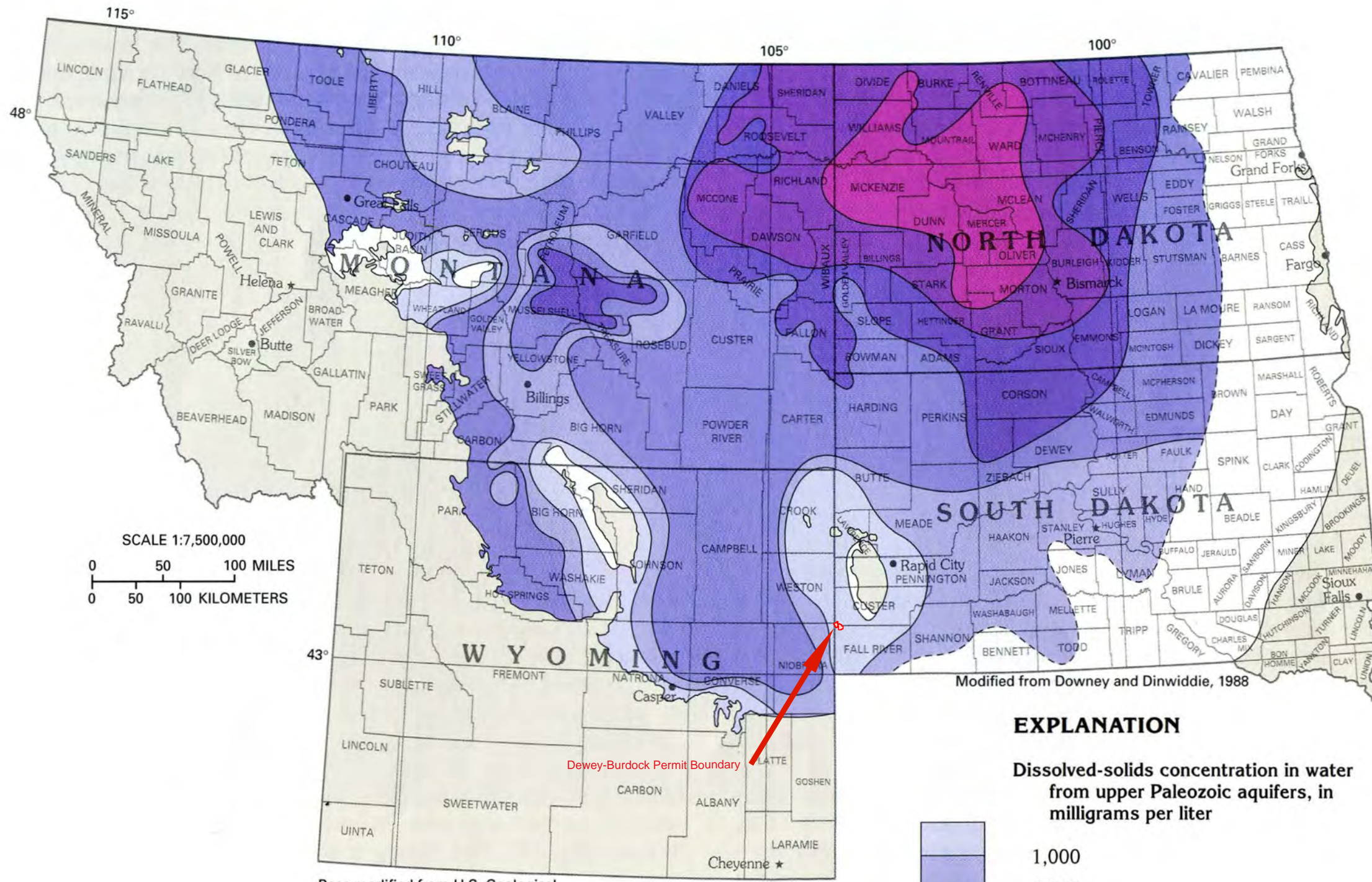
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Figure D-6  
Regional Groundwater Flow Pattern in Upper Paleozoic  
Aquifer System, Powder River and Williston Basins  
2010 Dewey-Burdock Class V Permit

|                             |                     |
|-----------------------------|---------------------|
| Scale: See Bar Scale        | Date: March 2010    |
| 2010_DB_Class_V_Fig_D-06.ai | By: JLM Checked: HD |

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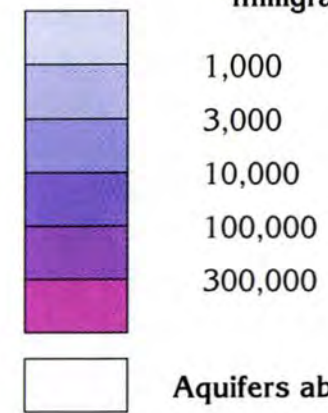


Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972

Modified from Downey and Dinwiddie, 1988

**EXPLANATION**

Dissolved-solids concentration in water from upper Paleozoic aquifers, in milligrams per liter



From: Ground Water Atlas of the United States, Segment 8 MT, SD, ND & WY, Hydrologic Investigations Atlas 730-I USGS (by Whitehead, 1996)


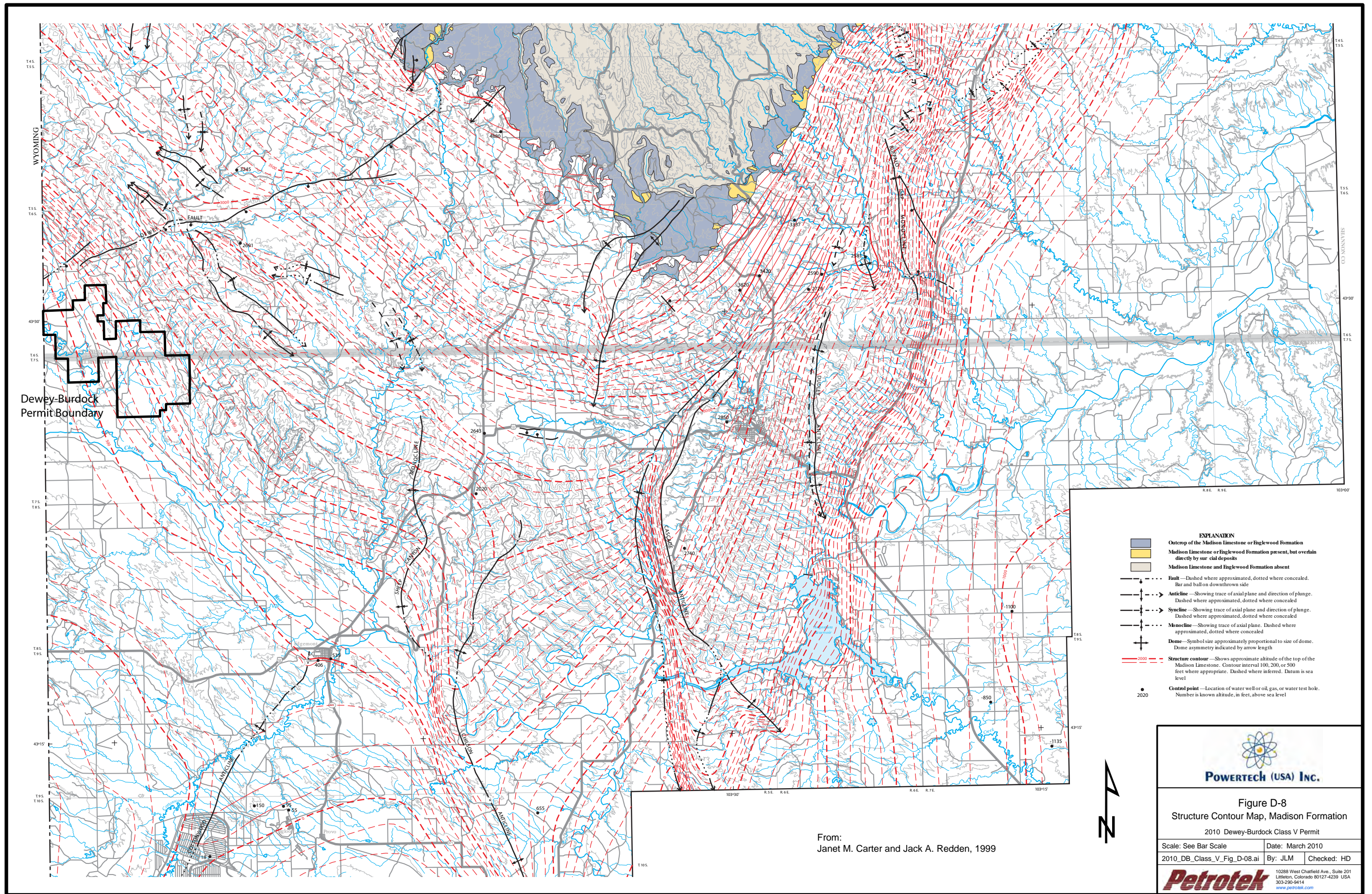
  
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Figure D-7  
 Dissolved Solids Concentrations in Upper Paleozoic Aquifer System, Powder River and Williston Basins  
 2010 Dewey-Burdock Class V Permit

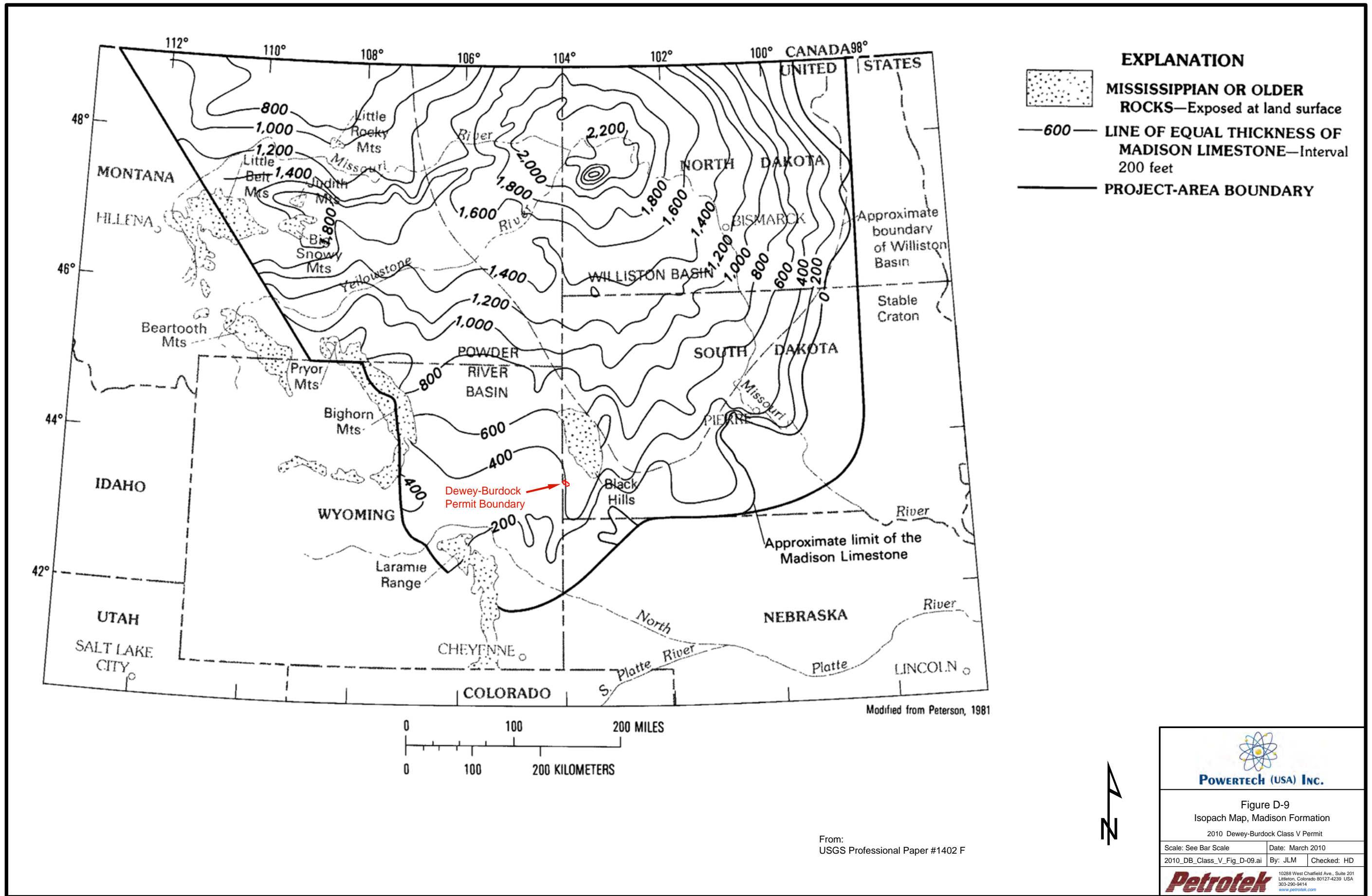
|                             |                        |
|-----------------------------|------------------------|
| Scale: See Bar Scale        | Date: March 2010       |
| 2010_DB_Class_V_Fig_D-07.ai | By: JLM    Checked: HD |

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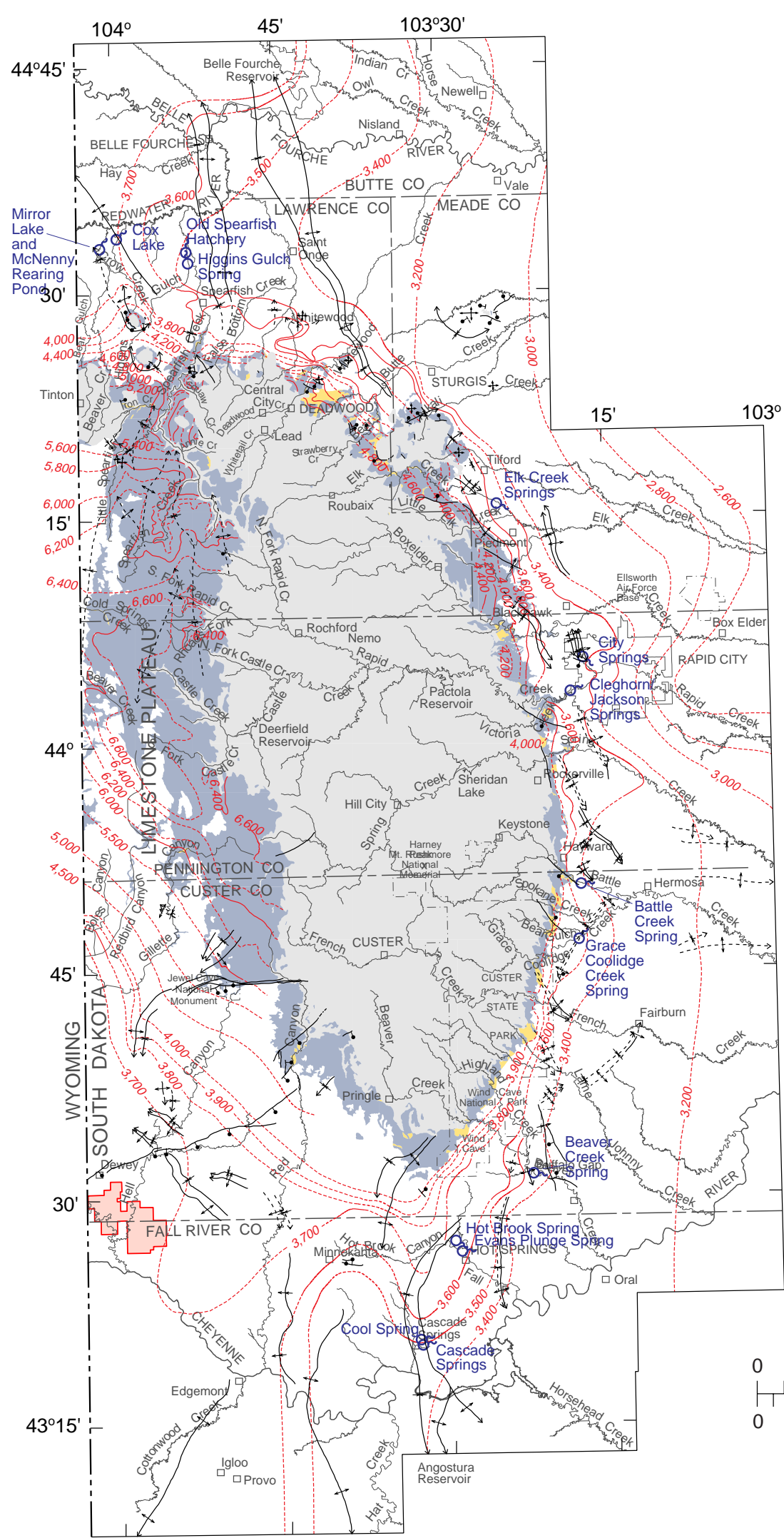


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Figure D-9  
Isopach Map, Madison Formation  
2010 Dewey-Burdock Class V Permit

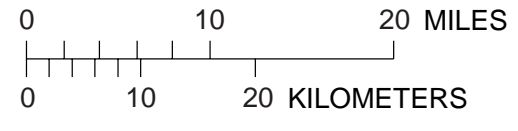
|                             |                       |
|-----------------------------|-----------------------|
| Scale: See Bar Scale        | Date: March 2010      |
| 2010_DB_Class_V_Fig_D-09.ai | By: JLM   Checked: HD |

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- EXPLANATION**
- OUTCROP OF MADISON LIMESTONE (from Strobel and others, 1999)
  - MADISON LIMESTONE PRESENT, BUT OVERLAIN BY SURFICIAL DEPOSITS (from Carter and Redden, 1999d)
  - MADISON LIMESTONE ABSENT (from Carter and Redden, 1999d)
  - POTENTIOMETRIC CONTOUR-- Shows altitude at which water would have stood in tightly cased, nonpumping wells (modified from Strobel and others, 2000a). Contour interval 100, 200, or 500 feet, where appropriate. Dashed where inferred. Datum is sea level
  - FAULT--Dashed where approximated. Bar and ball on down-thrown side
  - ANTICLINE--Showing trace of axial plane and direction of plunge. Dashed where approximated
  - SYNCLINE--Showing trace of axial plane and direction of plunge. Dashed where approximated
  - MONOCLINE--Showing trace of axial plane. Dashed where approximated
  - + DOME--Symbol size approximately proportional to size of dome. Dome asymmetry indicated by arrow length
  - o ARTESIAN SPRING


Base modified from U.S. Geological Survey digital data, 1:100,000, 1977, 1979, 1981, 1983, 1985  
 Rapid City, Office of City Engineer map, 1:18,000, 1996  
 Universal Transverse Mercator projection, zone 13



**Legend**

- Dewey-Burdock Permit Boundary

From:  
 Water-Resources Investigations Report 02-4094  
 (modified by Driscoll et al., 2002)



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Figure D-10  
 Potentiometric Surface of the Madison Formation  
 and Locations of Major Artesian Springs  
 2010 Dewey-Burdock Class V Permit

|                             |                       |
|-----------------------------|-----------------------|
| Scale: See Bar Scale        | Date: March 2010      |
| 2010_DB_Class_V_Fig_D-10.ai | By: JLM   Checked: HD |

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