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, Pc, 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:

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

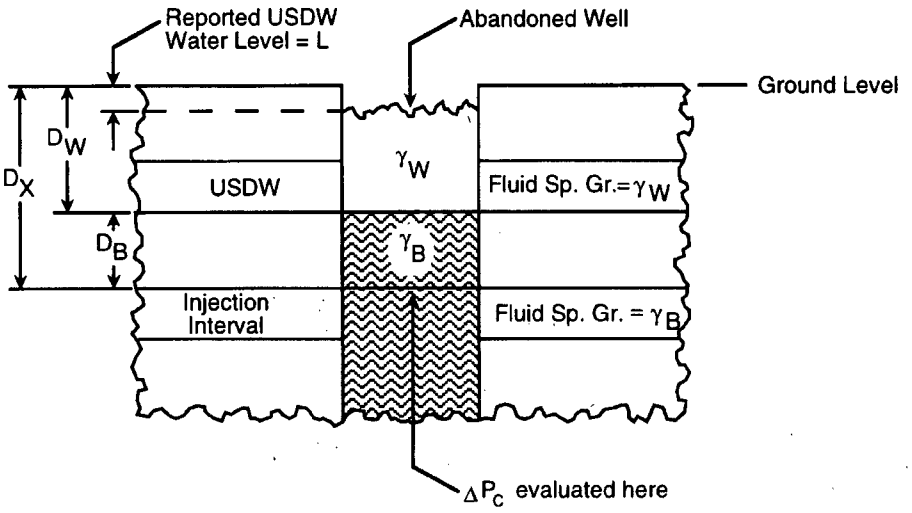
where: $D_B = D_x - D_w$

and the pressure rise is then:

$$Pc = 0.433\ [\ y_B D_B + y_w(D_w - L)] - Po$$

where Po 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:

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

or:

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

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:

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

or:

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

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).

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

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:

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

or:

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

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:

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

or:

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

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).

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

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:

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

or:

$$Pc = 164.7\ psi$$

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).

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

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:

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

or:

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

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).

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

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

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)
Minnelusa to Unkpapa/Sundance				200	1.008	695	1.001	1615	920	-29	617.6
Pc =	97.1	psi									
Minnelusa to Madison				200	1.008	-560	1.001	2205	2765	-200	875.1
Pc =	165.6	psi									
Deadwood to Madison				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)
Minnelusa to Unkpapa/Sundance				200	1.008	695	1.001	1950	1255	-29	763.8
Pc =	96.1	psi									
Minnelusa to Madison				200	1.008	-560	1.001	2540	3100	-200	1,021.3
Pc =	164.6	psi									
Deadwood to Madison				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	Solve	psi		
q =	flowrate (STB/d)	2,571.43	bbl/d		
B =	formation volume factor (RB/STB)	1.01	RB/STB		
u =	viscosity (cp)	0.74	cp		
k =	permeability (md)	150	md		
h =	reservior thickness (feet)	164	feet		
por =	formation effective porosity (percent)	0.21	fraction		
ct =	total matrix and fluid compressibility (1/psi)	6.50E-06	psi-1		
rw =	radius (feet)	Variable	feet		
t =	injection time (hours)	87660.0	hours	=	10.00 years
s =	skin factor (units)	0.0			

Term 1 -70.6(qBu/kh)

Term 2 (por*u*ct*rw^2/kt)

Injection Rate (gpm) = 75

dp = Term 1 * ln(1688.388*Term 2)

	Radius (ft)	Term 1	Term 2	[ln (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

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

TABLE A-4 Calculated Pressure Rise vs. Distance (Diffusivity Equation) - Deadwood 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	Solve	psi		
q =	flowrate (STB/d)	2,571.43	bbl/d		
B =	formation volume factor (RB/STB)	1.01	RB/STB		
u =	viscosity (cp)	0.67	cp		
k =	permeability (md)	75	md		
h =	reservior thickness (feet)	85	feet		
por =	formation effective porosity (percent)	0.11	fraction		
ct =	total matrix and fluid compressibility (1/psi)	7.00E-06	psi-1		
rw =	radius (feet)	Variable	feet		
t =	injection time (hours)	87660.0	hours	=	10.00 years
s =	skin factor (units)	0.0			

Term 1 -70.6(qBu/kh)

Term 2 (por*u*ct*rw^2/kt)

Injection Rate (gpm) 75

dp = Term 1 * ln(1688.388*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

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	

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

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^3)

r = (Q/((pi)*h*porosity))^0.5

Elapsed Time (yrs)	Qt (ft3)	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 (vl):
vl = (KI)/porosity where I = hydraulic gradient
K = 4.670 ft/d

Hyd. Gradient Displacement = (vl)*(time)

Elapsed Time (yrs)	Injection Displacement Ri (ft)	Hyd. Grad. Displ. Rg (ft)	Total Fluid Displacment 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^3)

r = (Q/((pi)*h*porosity))^0.5

Elapsed Time (yrs)	Qt (ft3)	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

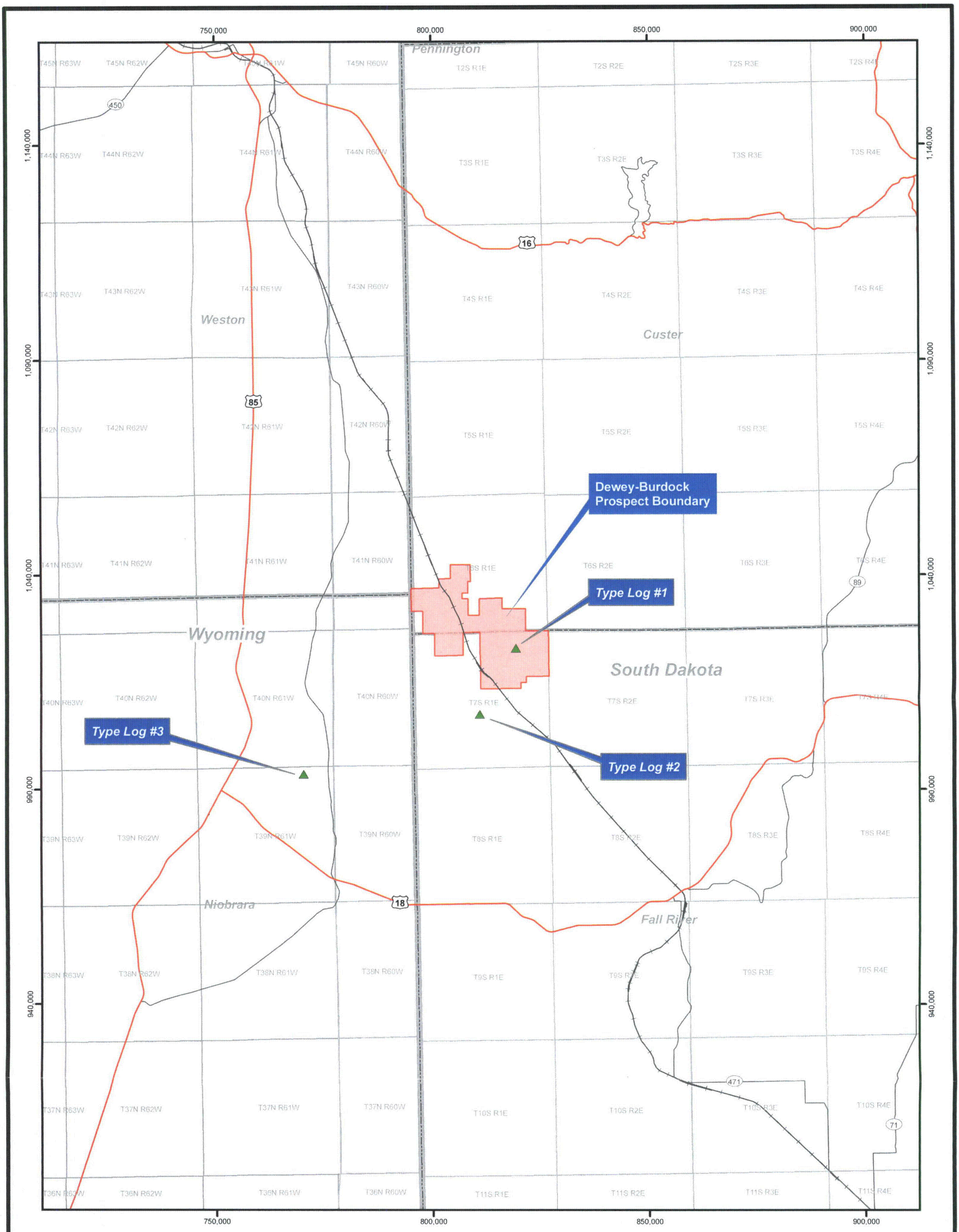
ASSUME: Regional gradient = 0.0001 ft/ft (10 ft/mile)

Linear velocity (vl):
vl = (KI)/porosity where I = hydraulic gradient
K = 4.670 ft/d

Hyd. Gradient Displacement = (vl)*(time)

Elapsed Time (yrs)	Injection Displacement Ri (ft)	Hyd. Grad. Displ. Rg (ft)	Total Fluid Displacment 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

N

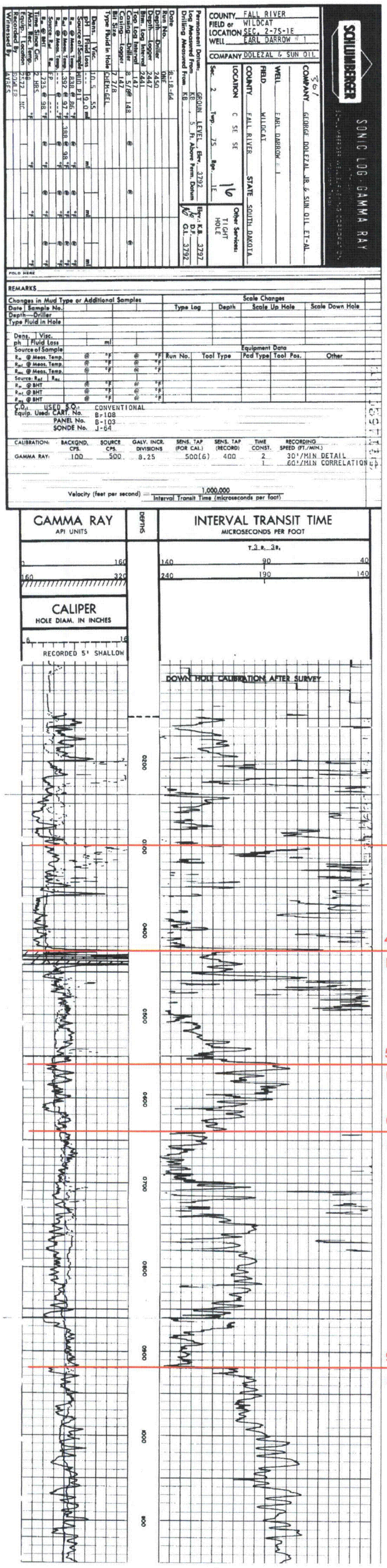
0 2 4 6 8 Miles

Powertech (USA) Inc.

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

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



Powertech (USA) Inc.

Figure A-2
Black Hills Area, South Dakota
Type Log #1
2010 Dewey-Burdock Class V Permit

Scale: NTS	Date: March 2010	
2010_DB_Class_V_Fig_A-02.ai	By: JLM	Checked: HD

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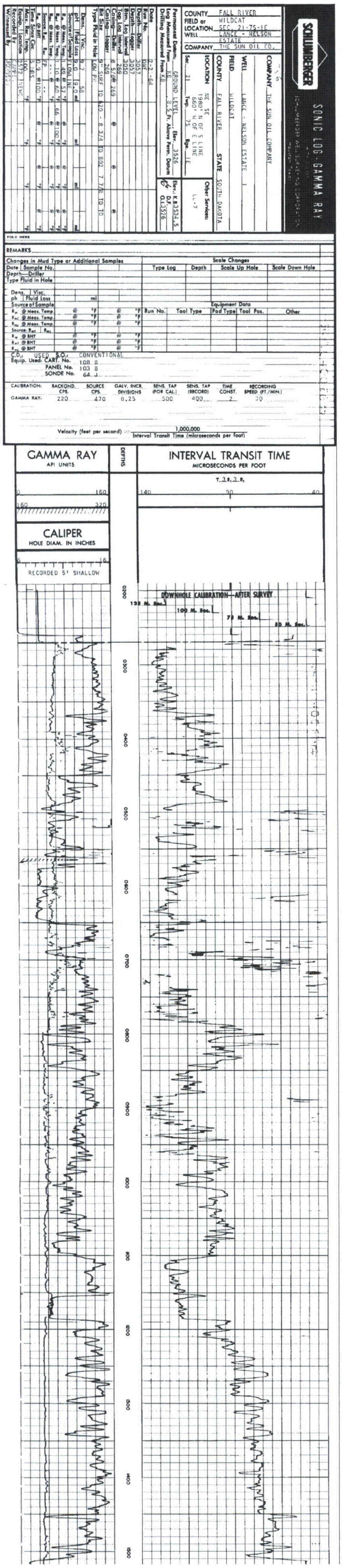

POWERTECH (USA) INC.

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

Petrotek
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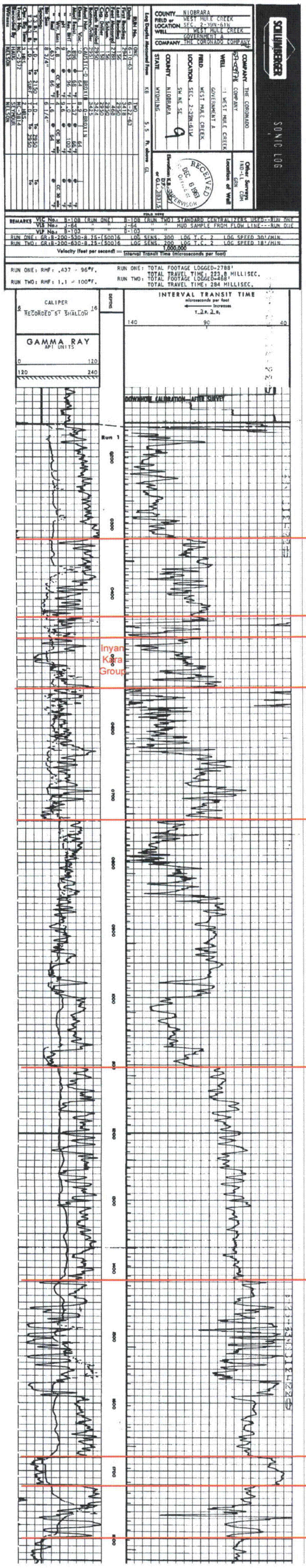

POWERTECH (USA) INC.

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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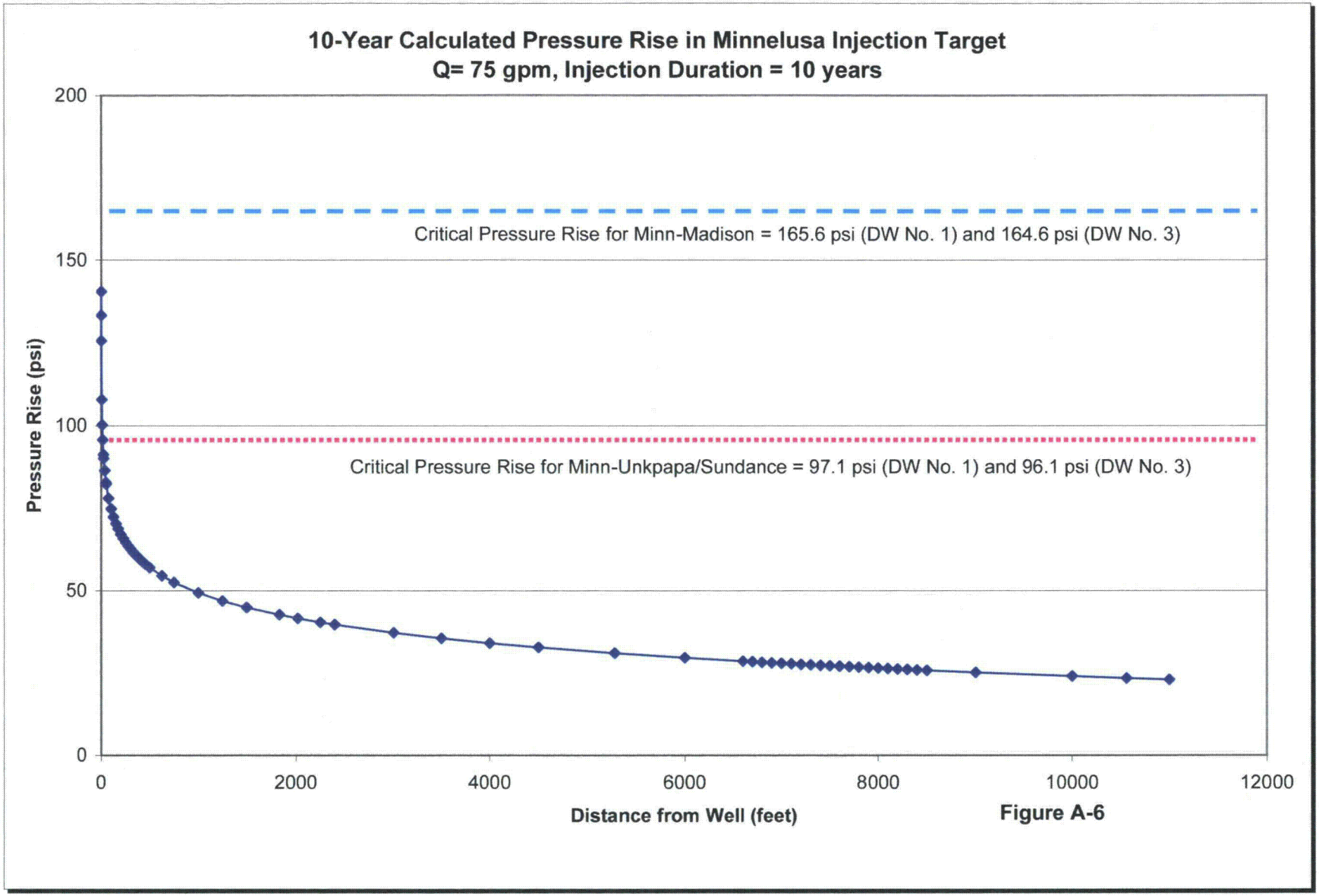
10-Year Calculated Pressure Rise in Minnelusa Injection Target
Q= 75 gpm, Injection Duration = 10 years
Critical Pressure Rise for Minn-Madison = 165.6 psi (DW No. 1) and 164.6 psi (DW No. 3)
Critical Pressure Rise for Minn-Unkpapa/Sundance = 97.1 psi (DW No. 1) and 96.1 psi (DW No. 3)
Pressure Rise (psi)
200
150
100
50
0
0
2000
4000
6000
8000
10000
12000
Distance from Well (feet)

Figure A-6

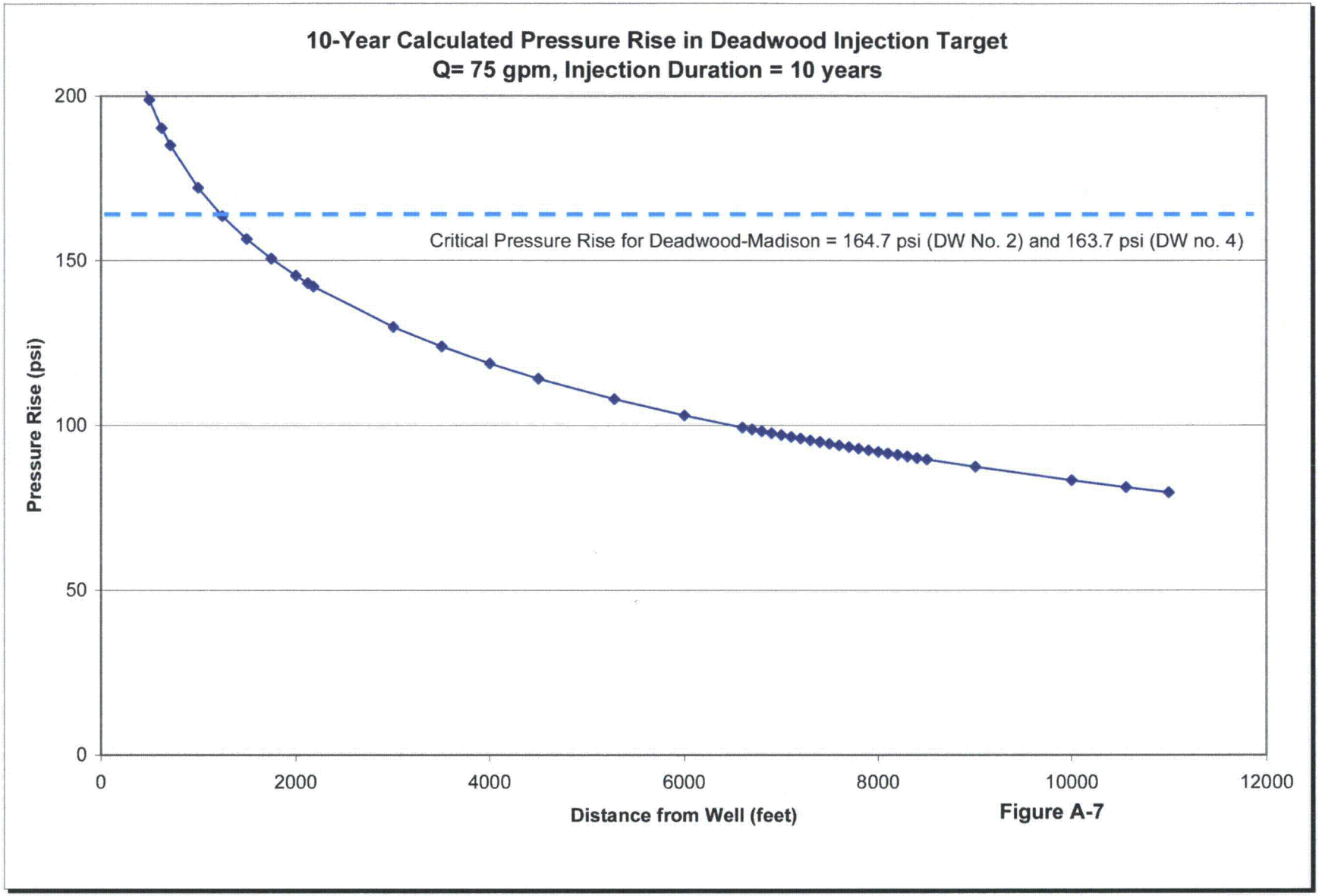
10-Year Calculated Pressure Rise in Deadwood Injection Target
Q= 75 gpm, Injection Duration = 10 years
Critical Pressure Rise for Deadwood-Madison = 164.7 psi (DW No. 2) and 163.7 psi (DW no. 4)
Pressure Rise (psi)
200
150
100
50
0
0
2000
4000
6000
8000
10000
12000
Distance from Well (feet)

Figure A-7